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**A Comparative and Analytical Study
of Visual Depth Perception**

By

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A COMPARATIVE AND ANALYTICAL STUDY OF
VISUAL DEPTH PERCEPTION¹

RICHARD D. WALK

AND

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George Washington University

Cornell University

*"descent and fall
To us is adverse."*

—Milton, *Paradise Lost*, Book ii.

ONE of man's strongest fears is the fear of high places and falling. The paratrooper standing in the door of his airplane waiting to jump, or the steel worker on the girders of a rising skyscraper are dramatic cases of fearful situations. Nearly all adults have felt apprehensive of height when looking down from a tall building or into a gorge, when balanced at the top of a high ladder or preparing to jump from a high diving board.

What is the basis of such a fear? Watson (1919), in his early studies of instinct in the newborn human infant, found that loss of support was a critical stimulus for fear. Loss of support for terrestrial animals means falling, the sudden cessation of the upward push of the ground on the skin, the cessation of the downward pull of gravity on the statoliths of the inner ear, and the

simultaneous cessation of the stretching of the body's antigravity muscles. The stimuli are tactal, vestibular, and kinesthetic. Falling, for most animals, is in fact dangerous. The changes in stimulation which inform the animal that he is falling accordingly arouse a variety of reflex postural reactions and a feeling of fear.

For adult animals who move about only on the ground, the danger of falling is confined to certain locations which might be called "falling-off places." At such a place, the level ground drops off to a lower level, making an edge, or cliff. The ability to detect a cliff by vision would be very useful, for it would provide the animal with the means of detecting a *potential* loss of support. If vision provided a means of detecting a cliff, it could function to preserve animals from falls. The theory of the evolution of species should predict that such a discrimination might develop in terrestrial animals and that it would be effective by the time the animal was ready for independent locomotion.

For visual detection of a drop-off, light to the animal's eyes must provide information to differentiate the drop-off from the surface on which the animal stands; it must provide stimulation for an edge, and ideally for gradations of depth below the edge. It is a fact of optics that if two surfaces at different heights are textured or patterned similarly, a difference in density of optical texture will be present in the light projected to the animal's eyes (Gibson, 1950, 1958).

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Priority of authorship of this monograph was determined by the toss of a coin.

Figure 1 shows diagrammatically such a situation.

The same situation provides a second kind of differential stimulation for depth discrimination if the animal moves. Head movements or a change in his position as the animal looks will produce motion parallax. The velocity of angular motion of texture elements at the line of the optic array corresponding to the edge of the platform (or the animal's nose or feet) will be different from the velocity of elements of the surface below. Motion parallax (differential velocity of elements in the array) will increase as the drop increases. There will be a velocity difference, then, between the ground and the surface below, which will characterize the relative depth of the surface below—the amount of the drop-off. This velocity difference produced by the animal's own movement is potentially a highly effective kind of information about the relative depth downward of a surface.

Binocular parallax is another potential differential stimulus for depth. This is definitely a cue for depth discrimination in humans, since they have overlapping visual fields and conjugate eye movements. All animals with whom this research is concerned have some overlapping of visual fields (though degree of overlapping differs greatly among species), but the extent to

which convergence and conjugate eye movements are utilized is largely unknown. (Duke-Elder, 1958; Walls, 1942). The other "cues" to depth are probably irrelevant here. The informative value of accommodation has been questioned under any circumstance.³ Looking downward, vertical position in the field no longer comes in as a source of information, as it would looking straight ahead. Aerial perspective, brightness, etc., would be inoperative, unless the drop was very great indeed.

But the two stimulus variables of density difference and velocity difference in elements of the two surfaces are available for any animal with an eye to detect a drop-off. Whether most animals actually do so, at what age, and under what conditions, is the topic of this research.

If the surface below the animal is literally untextured or homogeneous, there would be, presumably, no optical stimulation for surface perception. When there is no visible surface to descend on, the animal should not descend if his behavior is truly adaptive. Water (without ripples) might provide such a surface in nature, and tend to be avoided by terrestrial animals. It might, on the other hand, be approached by an aquatic animal, just as air (untextured light) would indicate a safe path for flying for a bird.

The problem with which this monograph is concerned is the discrimination, by vision alone, of depth downward at an edge. Some of the questions to be answered are the following: Is the discrimination present in animals of different species and different ages? Can it be detected by tendency to avoid a drop-off? Is the avoidance tendency greater, the greater the drop? What conditions or cues are actually operative in making the discrimination? And what is the role of visual experience in different species in promoting the discrimination?

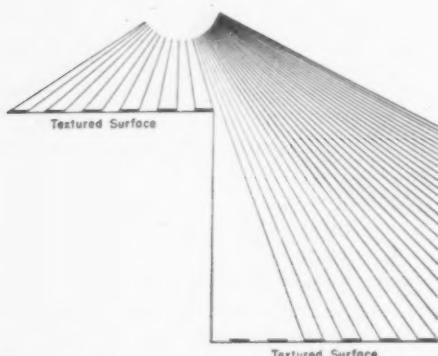


Fig. 1. If an animal stands on the raised floor on the left, with an identically textured surface below on the right, the light rays reaching his eye will differ in density, a finer density characterizing the surface farthest below the eye.

³ Van Tuyl (1937) in a study of monocular perception of distance found that there was no indication of an "immediate and familiar sensation of distance," and that the majority of *Ss*, when forced to rely on accommodation and convergence alone, could not achieve any consistent accuracy even after considerable practice.

HISTORICAL BACKGROUND

Several methods used in the study of animal behavior have taken for granted that an animal will discriminate and avoid a drop-off. The elevated maze is useful because the rat does not jump off. The jumping stand requires that the animal gauge his jump to a platform, and that he avoid falling into a net below. But only a few studies have been made of the avoidance of the drop itself. We shall refer arbitrarily to such a discrimination as perception of *depth*, to differentiate discrimination of depth downward, or a drop-off, from perception of distance ahead.

The earliest experimental study of this behavior appears to be Spalding's, in 1875. He blindfolded a baby pig at birth, later put it on a chair and removed the blindfold. It "knew the height to require considering, went down on its knees and lept down" (p. 507). The implication was that the piglet was able to gauge the force of the jump appropriate for the steepness of the drop correctly in spite of no previous visual experience. Since infant pigs are ambulant almost at once after birth, the early maturity of this capacity is highly adaptive.

Thorndike, in 1899, made a study of instinctive reactions in the newly hatched chick. His procedure included putting the chick on a pedestal a certain number of inches above a box containing other chicks. The question was: at what heights would the chick, motivated by the sight and chirping of its fellows, jump down; and at what height would it refrain from jumping. At 10 inches or less, the average chick 95 hours old jumped immediately; at 16 inches, he waited up to 3 or 4 minutes, and so on, until at 39 inches, the chick would not jump down. Thorndike (1899) concluded that "at any given age the chick without experience of height regulates his conduct rather accurately in accord with the space-fact of distance which surrounds him" (p. 284).

An experiment by Kurke, in 1955, made use of a similar technique. The chick jumped from a platform of variable height to join a group of cheeping chicks. The platform was raised to 21 inches at the start, and the chick

was given a 30-second trial at this height. If it did not jump, the platform was lowered by 2-inch steps until it did. Normal chicks 3 days old jumped at a mean height of 3.4 inches. Dark reared chicks 1 and 2 days old would not leave the platform, but dark reared chicks 3 days old jumped at a mean of 2.4 inches. A group given "enforced vertical experience" in the brooder, run at 10 days, jumped at a mean height of 6.4 inches. These chicks were provided with a platform and ramps 15 inches high in the brooder. They were compared with a "restricted" group which had wire mesh just over their heads in the brooder. The restricted group jumped at a significantly lower height. What conclusion should be drawn from this comparison is not clear for two reasons. The chicks provided with ramps and platforms had far more opportunity to develop motor coordination. Furthermore, the 30-second trial length was probably much too short. Thorndike's research (and our own) showed that the chick often hesitates up to 10 minutes before going anywhere.

The depth discrimination of turtles presents an especially interesting problem, since the same type of adaptation might not be expected of both land and aquatic species. Yerkes, working at the New York Zoological Gardens in 1904, made a study of the space perception of three species of tortoises, one aquatic (*Chrysemys picta*), one terrestrial (*Terrapene Carolina Linnaeus*), and one which is both aquatic and terrestrial (*Nanemys guttata*). The turtle was placed in the middle of a board elevated 30, 90, or 180 centimeters above a black net, and its time to leave the board measured. The three species reacted differently; the terrestrial turtle and the one of mixed habits failed in a majority of cases to leave the board at all during a 60-minute period when it was raised to a height of 180 centimeters, but all except one of 40 aquatic turtles came down. All three species, however, showed increasing hesitation with increasing height. Yerkes (1904) concluded that

hesitation in the presence of the void increases as we pass from the strictly water forms to those which are land inhabiting . . . [and that]

total inhibition of the reaction, i.e., failure to crawl over the edge of the board in 60 minutes, appears at a much less height for the land species than for the waterland and water forms (pp. 20-21).

According to Yerkes, the land turtles "manifested fear" of the heights. For the aquatic turtles, presumably, jumping off an edge would have been associated with landing in water, a place of safety. When blindfolded, these animals pushed off any height with no hesitation; but *T. Carolina*, the land turtle, was inactive when blindfolded.

Depth discrimination of rodents was reported on by Waugh, in 1910. The mouse was placed on a pedestal at varied heights, and its time to jump down measured. With two mice, he found a graded increase of time as the pedestal was raised from 4 to 18 centimeters. The column supporting the pedestal was visible. He then changed the platform so that it hung from a higher surface, eliminating the pedestal, and placed a sheet of glass 4 inches below it but still above the floor. The animal did not perceive the surface of the glass and behaved as if the surface below it were that of the floor. The times were graded with distance when a board was lowered below the disk.*

In 1932, Russell showed that rats on a jumping stand would gauge the force of a jump according to the distance of the target. The jumping stand involves discrimination of both depth downward and distance ahead. There is edge avoidance and gap jumping—a notorious conflict situation, requiring considerable persuasion to make the animal jump. Russell gave 10 trials at different distances in chance order. Force and distance were reported to be directly related in the case of every rat. Albinos were somewhat inferior to pigmented rats (they "jumped short" and their curves did not rise as

steeply). Monocular animals performed as well as binocular ones. As distance increased, so did "disinclination to jump."

The same procedure was applied by Lashley and Russell in 1934 to rats which had been raised in a darkroom. For a series of distances, force was nearly as accurately graded as it was in animals raised under the usual lighting conditions. The dark-reared animals were inferior in motor coordination (take-off and landing) but force was just as precisely graded as in normally reared animals. Lashley and Russell concluded that there is an innate mechanism by which the relative force exerted is immediately adjusted to relative distance, and that discrimination of depth is not dependent on past experience.

The conclusions drawn from this experiment have been criticized on several grounds. It has often been pointed out that the dark-reared animals had to be trained in the light to perform on the jumping stand, thus providing opportunity for visual experience before the depth judgments were tested. Greenhut and Young (1953) repeated Russell's experiment (although they added shock as an incentive), and concluded that "distance is not appreciated visually" and that, with a random order of presentation of distances, there was no correlation of force and distance. They also argued that jump force is a poor criterion because it is not always correlated with an accurate jump. Since they used shock and reported that their animals were "emotionally disturbed," it is not unreasonable that Russell's results were not duplicated. Their criticisms, however, make confirmation by another technique important.

Surprisingly little experimental work has been done on space perception—especially depth downward—in large animals. Warkentin and Smith (1937) studied development of visual acuity in the cat, and reported that visual placing reactions of the forelimbs occurred at a mean of 25 days. The visual placing is presumably a sign of distance perception; whether it is related to discrimination of a drop downward remains to be seen. It is interesting to note,

* Waugh also tried a sort of obstacle test for perception of distance of objects *ahead* of it (the animal had to swerve to avoid the objects). Many errors were made in this situation. He noted that head movements "giving several points of view of the object, each from a different angle" seemed to accompany right choices, suggesting that motion parallax was operating. Other experiments with rodents on distance ahead are those of Robinson and Wever (1930) and Greenhut (1954).

with regard to this response, that Riesen and Aarons (1959) found the visual placing reaction absent in cats reared in the dark until 6 weeks of age. Dark-rearing may, therefore, prevent normal maturation of the capacity for depth discrimination in the cat, although it appears not to prevent depth discrimination in the rat and the chick. Confirmation of such a differential result is needed.

The primates, at least at a mature stage, presumably have good discrimination of a visual drop, but there has been little developmental work on either apes or human children. Riesen's dark-reared chimpanzees (Riesen, 1950) were slow in learning to avoid the approach of a striped disk which gave an electric shock if it touched them, but no systematic test of visual depth discrimination was made.

There are no studies at all of perception of a drop-off in human infants and young children. In fact, only a few studies of discrimination of distance ahead exist (Denis-Prinzhorn, 1960; Johnson & Beck, 1941; Updegraff, 1930; and, by inference, Cruikshank's 1941 study of size-constancy in infants). In human adults, it is interesting to note a result of an experiment with airborne trainees (Windle, Ward, Nedved, & Nathan, 1956). Trainees were required to learn proper aircraft exit techniques by jumping from a tower that permits a free fall of 8 feet before the jump is snubbed. Different groups were required to make the jumps from each of three heights (18 feet, 26 feet, and 34 feet). Although the physical fall experienced by each group is the same and only the perceived visual height differs between groups, a cumulative curve, day by day of training, showed that more satisfactory jumps were made, the lower the height. Hesitation (and poor technique) in jumping increased the greater the height of the platform from the ground.

Clearly, there are many gaps in our knowledge of behavior when an animal or a human infant or child stands at the verge of a sheer drop. Whether, how soon, and by what optical information he avoids the drop are questions to be answered.

APPARATUS AND PROCEDURE

To conduct a comparative study of the visual discrimination of depth downward, an apparatus fulfilling the following requirements is necessary: it must permit control of all cues other than optical ones, no pretraining should be required, and substantially the same apparatus should be adaptable for testing many different species.

Of the kinds of apparatus used in the experiments reviewed in the introductory section, none satisfied these requirements completely. For instance, the force of jump measure used by Russell (1932) required extensive pretraining; it may have allowed the subject to utilize some cues other than visual ones, and it is adaptable only for organisms which can be trained to jump. The graduated series of heights used by Waugh with mice, Thorndike and Kurke with chicks, and Yerkes with turtles, can be used for a variety of animals, but it might be dangerous for subjects of poor locomotor ability. Furthermore, some nonvisual cues (e.g., echolocation) might be utilizable. And finally, a measure of refusal to jump down, alone, might be contaminated in some experiments by side effects of previous rearing conditions (e.g., dark-rearing or isolation, which increase "emotionality"—Gibson, Walk, & Tighe, 1959).

The apparatus designed for the present experiments, which we named the "visual cliff," uses the principle of a drop-off or graduated heights, but gives the animal a *choice* between a short drop-off on one side of a center board and a long drop-off on the other side. A terrestrial animal, if it detected the difference, should prefer the short drop-off at a safe depth to the long drop-off at a dangerous depth. To eliminate nonvisual cues that might permit detection of the difference, such as auditory, olfactory, or temperature differentials⁵ from near or distant surfaces, a sheet of glass was inserted under the center board where the organism was placed, so as to extend out-

⁵ Of these cues, the only one reliably demonstrated to be a cue for distance is echolocation (Griffin, 1958; Riley & Rosenzweig, 1957).

ward across both the shallow ("safe") drop and the deep ("dangerous") one. The glass was placed over the shallow side as well as the deep side to equate stimulation produced by the glass itself, if any (e.g., reflections), and to equalize tactual cues for locomotion.

Patterned material (wallpaper, linoleum, etc.) could be placed directly under the glass on the shallow side and on the floor below, at any desired distance, on the deep side. Information in the light coming to the animal's eye from the patterns on either side, in combination with stimulation produced by the animal's own motion and ocular equipment constituted the stimulus basis for visually differentiating the two sides. Figure 2 shows diagrammatically the situation created by the apparatus.

In summary, the subject was allowed to descend to either an optically shallow or to an optically deep surface from a center board between the two surfaces. If the subject could not or would not locomote, of course no data could be obtained.

The general procedure was as follows: The animal was placed on the center board, normally by hand, although the first experiments with rats placed the animal on the board in a small box to eliminate handling

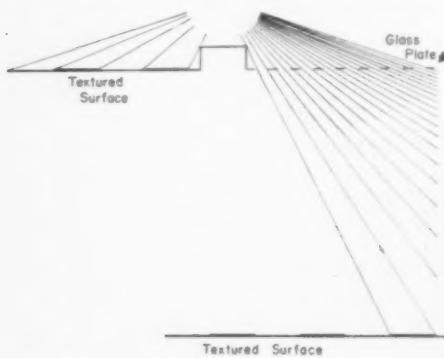


Fig. 2. Diagram of the visual cliff, in cross section. (The animal is placed on a raised board in the center. On the left side is a patterned surface only a short drop below his feet—the shallow side—and on the right is the same patterned surface placed much farther below—the deep side. Glass extends across both sides from the base of the center starting board.)

bias. To equate for position preferences half of the animals were started from one end of the board, half from the other. Observation periods varied for each species but were adequate to permit descent from the board. Descent to the glass surface was whenever possible left to the natural exploratory tendency of the subject. At the end of the observation period, the animal was removed and the board and glass surface cleaned with a damp sponge. To equate odor cues the sponge was used on the glass surface over both the shallow and deep sides regardless of the side of descent.

Controls will be described later that were run to make sure no extraneous stimulation might cause a preference for one side or the other.

Three models of the visual cliff were made. The first, a relatively crude model, served to explore this method of testing depth discrimination. A second one was then built which permitted more precise control of stimulus factors. A third one was constructed for testing larger animals.

Cliff Model I

This apparatus, shown in Figure 3, consisted of four ring stands with clamps that supported two sheets of glass (24" x 32") parallel to the floor and 53" above it. An unpainted board 24" long x 4" wide x 3" high divided the glass into two equal parts. Between the sheets of glass on one side of the board (the "shallow" side) was inserted a sheet of patterned wallpaper of 8" green, white, and grey checks. The same wallpaper was placed on the floor and on the walls below the glass surface. Above the floor of the glass surface, cheesecloth surrounded the apparatus to



Fig. 3. Photograph of visual cliff, Model I. (The experimental testing situation is shown to the left and a control condition where the textured surface is placed under the glass on both sides of the center board is shown to the right. The wallpaper pattern on the shallow and deep sides is the same.) (Reprinted from *Science* by permission)

shield the experimenters partially from the subject's view. The apparatus was placed in a corner of the room and the subject descending from the board toward the shallow side went toward the observers. All animals used in this apparatus were placed on the center board in a box to avoid any handling bias. The apparatus was illuminated from above by fluorescent lighting and additional illumination was supplied the deep side from below to equate the two fields in brightness. Brightness readings are shown in Table 1.

Cliff Model II

The apparatus was modified in the second model to eliminate visible supports by hanging the entire apparatus from ceiling supports. The modifications also made for better control of illumination, less reflection from the glass, and provided for a continuous visible texture on the deep side. This apparatus permitted much more precise experimental control of the optical stimulation.

The apparatus, which is schematically shown in Figure 4, consisted of a hollow enclosed box with a floor of glass. The walls were of $\frac{1}{4}$ " pine and the floor was two $16" \times 20"$ pieces of glass; the outside dimensions were 32" long, 20" wide, and 9 $\frac{1}{2}$ " high. The glass was supported by right angle aluminum $\frac{1}{4}" \times \frac{1}{4}"$ fastened to the side of the walls and protruding under them. An additional piece of aluminum provided support for the textured surface to be placed directly under the glass on either side of the center board. These textured

patterns were fastened to masonite pieces $16" \times 20"$ that slid under the glass. The center board measured 18" long, 3 $\frac{1}{2}$ " wide and its height could be varied from $\frac{1}{2}"$ to 3 $\frac{1}{2}"$. Both the box and the center board were painted a flat grey.

Two small bulbs fastened to the side of the apparatus with reflectors above them supplied additional illumination, if required, to the textured surface on the floor. The textured surface on the floor covered enough of the floor of the room away from the center board to provide a continuously textured surface on the deep side. When the height of the apparatus was set at 10" the textured material extended 5' away from the center board and 1' underneath it; at the 25" height the textured surface was also taped 15" up the far wall of the room itself which was 6' from the center board.

The box containing the apparatus hung from two parallel ceiling beams of $2" \times 4"$ pine, 100" long, placed 32" apart and 84" above the floor. The box hung from the ceiling beams by two adjustable sliding wooden supports measuring $\frac{3}{4}" \times 3\frac{1}{2}" \times 80"$, one fastened at each end of the cliff apparatus and sliding into grooves in the ceiling beams. The adjustable supports were held at a desired height by the insertion of a large nail through a hole in the board above the grooves.

The ceiling above the apparatus consisted of a sheet of white cotton cloth tacked to the underside of the ceiling beams across the width of the room and hanging 4' down toward the floor. A piece of $22" \times 28"$ cardboard was attached to each suspending support. The cloth and the cardboard served to diffuse the illumination from the ceiling of the apparatus and, in addition, to shield the details of the apparatus and the experimenters from the subject's view.

The illumination from above was supplied by two 150-watt bulbs hung at each end of the room

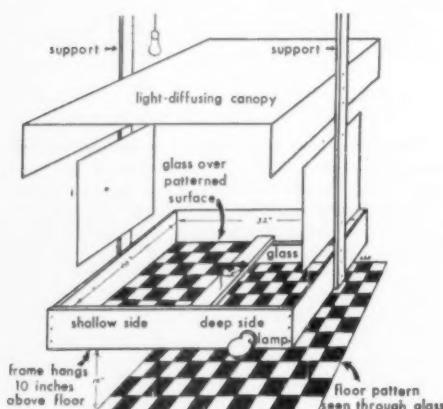


Fig. 4. Drawing of visual cliff, Model II. (The box containing the cliff is hung from the ceiling. The animal stands on a center board, looking toward the deep side. The shallow side is covered with a patterned material under glass. The identical patterned material covers the floor below, as far as the animal's vision can range from the center board. The glass extends out from the board over the deep side as well.)

TABLE 1

BRIGHTNESS READINGS TAKEN WITH WESTON MASTER III

Cliff Model	Reading
I (with small checked pattern)	
Shallow side	1.6
Deep side	1.4
II ($\frac{3}{4}$ " red checks)	
Shallow side	.8
Deep side	.8
III (green and white tile)	
Shallow side	3.2
Deep side	3.2

Note.—Multiplying the Weston reading by 4 gives an approximate foot-candle measurement (a reading 1.6 is about 6.4 ft-c.).

above the diffusing cloth. Aluminum foil was hung over a metal pipe 27" above the main supporting beams and fastened to them so as to make a tent-shaped roof. The aluminum foil concentrated the light so that the illumination came from the ceiling above the apparatus and little could be reflected from elsewhere in the room. The foil also served to diffuse the light evenly across the ceiling so that no single bright area or "hot spot" was reflected in the glass of the apparatus below. On the whole, the diffusion of light from the ceiling served to illuminate the apparatus homogeneously and to minimize reflections in the glass.

Experimenters observed from behind the cardboard at the shallow side.

Cliff Model III

This model of the visual cliff was designed to test larger animals and human infants. A table was constructed of 2" x 4" pine, measuring 8' long, 6' wide, and 40" high. Supporting legs were placed at each corner and in the middle of each long side where an additional supporting cross beam was also used. Two large pieces of Herculite glass 4' x 6' x 1" formed the surface of the table. Under the shallow side a 46" x 68 1/2" x 1" piece of composition plywood 1" below the glass was placed to support a textured surface, an irregular green and white pattern of linoleum tile that matched the floor. The same tile pattern was laid over the center board which measured 6' x 11 1/2" x 1".

The cliff table was entirely surrounded by an 8" high board of 1" pine to protect the subject from accidentally falling off the cliff.

Illumination was supplied by fluorescent lighting directly over the apparatus. The fluorescent lights were covered with brown wrapping paper to diffuse

the lighting more evenly over the ceiling and to minimize reflection of the lights from the glass. This model of the visual cliff is illustrated in Figure. 5.

BASIC EXPERIMENTS AND VALIDATION OF THE CLIFF

This section will be devoted to a report of basic experiments with the visual cliff and a number of control experiments run to provide validation for the technique. The purpose of all the control experiments was to demonstrate that the animals were responding to the visual cues provided by the textured surfaces at different depths below the animal. The possibility of choices depending on other factors, such as brightness, reflections, and position of the experimenters had to be ruled out. The experiments included here also varied textures, heights, and the apparatus design itself. The subjects for these experiments were all hooded rats (Long-Evans stock) reared in the laboratory colony. Hooded rats were chosen for their availability in large numbers, their small size which made control of apparatus and environmental factors practical, and the fact that their natural exploratory drive solved the motivation problem. A rat was never run more than once unless it is specifically stated in the experiment.

Original Experiment

The first experiment⁶ was run on the original apparatus (Model I). The measures taken were side chosen on first descent, time spent on either side, and number of crossings back and forth (if any). The textured material was directly under the glass on one side (shallow), 3" below the surface of the center board. On the other side (deep), the textured material was on the floor, 53" below the surface of the center board. The animal was placed on the center board and then observed for 5 minutes. A second group of animals was run under a control condition in which the textured paper was placed directly under the glass on both sides. The side which was deep for the experimental group is referred to similarly (Table 2) for this group as well, for purposes of comparison. If the animals had a preference for one side or the other, due to irrelevant factors such as the position of the experimenters, the

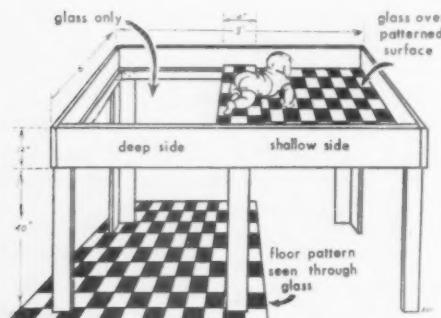


Fig. 5. Drawing of the visual cliff, Model III. (This cliff differed from Model II chiefly in size and strength. Because of its weight it was supported by legs. An infant is starting from the center board toward the shallow side. The entire floor of the room is covered with the checkered linoleum identical with that on the cliff.)

⁶ This experiment was reported in *Science*, June 1957.

control group's behavior should reveal it. The experimenters actually stood closest to the shallow side.

Results. It can be seen in Table 2 that the experimental group tended strongly to descend on the shallow side, did not cross back and forth at all, and passed a majority of its time on the same side. The preference for the shallow side is especially convincing in view of the closeness of the experimenters to that side.

The control group, on the other hand, showed no preference for either side in first descents, did in a number of cases cross back and forth, and spent more time on the side which was deep for Group E.

This experiment led us to the conclusion that hooded rats will avoid a visual cliff—a long visual drop-off as compared with a short one. It should follow, therefore, that animals placed on a center board with the textured surface far below the glass on both sides should be hesitant in descending either way. We next set up such an experiment. The same rats were run under two conditions: first, in the control condition already described, with the checked pattern directly under the glass on both sides; and second, in a new control condition with the checked pattern far below the glass on the floor on both sides. The animals were placed on the center board and observed for 3 minutes. The number of animals de-

TABLE 2
COMPARISON OF EXPERIMENTAL AND CONTROL
GROUPS ON THE VISUAL CLIFF APPARATUS

	Experimental group (N = 29)	Control group (N = 10)
Percentage descending on shallow side	88.5	50.0
Mean number of cross- ings in 5 minutes	0.0	1.70
Percentage of time on:		
Shallow	76.0	24.1
Deep	10.0	61.5
On Board	14.0	14.4

TABLE 3
NUMBER OF DESCENTS AND LATENCY OF DESCEND-
ING UNDER TWO CONTROL CONDITIONS, BOTH
SIDES IDENTICAL
(N = 11)

Control condition	Number of animals descending	Median latency (seconds)
Pattern directly under glass	9 (81.8%)	9
Pattern on floor	4 (36.4%)	120

scending in 3 minutes and the median time to descend are presented in Table 3.

As would be expected, the animals were much slower to descend when the patterned surface was on the floor (53" below) than when it was directly under the glass. The majority of animals did not descend at all in this condition, although they were being run for the second time.

Comparison of Different Patterns and Depths of Visual Surfaces

Following the first experiment, a new apparatus was built (Model II), as described in the previous section.

The animal's entire field of view was controlled by this apparatus. The old wallpaper pattern was replaced by three other patterns, in turn. One was a fine textured pattern in grey and white with rather low contrast. A second was a coarse textured pattern (4" squares) with higher contrast. The third was actually without pattern or texture—a light grey homogeneous surface. As in the previous experiment, the material was placed directly under the glass on one side and at some distance below on the floor on the other side. The center board was 4" high. Since the new apparatus could be raised and lowered, the fine texture was tried at two depths, 25" and 10" (Conditions A and B in Table 4). The coarse texture was placed in the basic experiment at 10" (Condition D). A control experiment was also run with the fine texture, with the material directly under the glass on both sides (Condition C). This was a replication of the earlier control experiment with the new apparatus and pattern. The other control (pattern on the floor below on both sides) was run with the coarse texture at a depth of 10" (Condition E).

TABLE 4

PLACE OF DESCENT AND MEDIAN LATENCY FOR ADULT HOODED RATS WITH DIFFERENT TEXTURES AND DEPTHS OF VISUAL SURFACE

Condition	N	Shallow side		Deep side		No descent
		%	Latency (seconds)	%	Latency (seconds)	
A. Fine texture 25" deep side	22	95	12	0		5
B. Fine texture 10" deep side	12	100	6.5	0		0
C. Fine texture 0" both sides	16	56.7	7	43.8	7	0
D. Coarse texture 10" deep side	15	93	17.5	0		7
E. Coarse texture 10" both sides	20	30	33	5	40	65
F. Untextured 10" deep side	20	35	7.5	40	10	25
G. Coarse texture 10" deep side, far side brighter	10	100	5	0		0
H. Reflection eliminated 10" deep side, coarse texture	20	90		10		0

The untextured homogeneous grey material was placed directly under the glass on one side, and 10" below on the other (Condition F). This condition provided a further control for extraneous cues. If any stimuli other than visual stimuli for depth were determining the preference for the shallow side, the preference should persist in this condition. If not, the two sides should be chosen about equally or the animal should remain on the board. In these experiments, the animals were placed on the board and then observed for 3 minutes. Median latency and place of descent were recorded. No animal was run in more than one condition.

Results. In Table 4 it can be seen that both textures, fine and coarse, were effective. The animals descended over 90% to the shallow side, and *none* descended to the deep side (Conditions A, B, and D). A 10" visual drop-off was just as effective for this preference as a 25" one.

When the fine texture was directly under the glass on both sides (Condition C), the preference disappeared, as it had in the previous control experiment. About 44% of the animals descended to the deep side, as contrasted with none in the experimental groups.

When the coarse texture was placed 10" below the glass on both sides (Condition E), 65% of the animals refused to descend at all in the 3-minute interval.

When the material under the glass was untextured (Condition F), 40% of the ani-

mals chose the deep side, 35% the shallow side, and 25% refused to leave the board. Since there was no visible grain in the surface (to the human eye, at least) this was not surprising. The prediction that there should be no preference for either side with a textureless surface was confirmed.

Brightness Control

When the main source of illumination was from above, the closest surface to the light source, which was the shallow side of the apparatus, received the most illumination. To balance bright-



—William Vandivert

Fig. 6. One of the control experiments showing a hooded rat on the board of Cliff Model II. (Plain, untextured grey paper lay under the glass on both sides. The grey surface to the right of the animal is actually 10" below the glass; that on the left of the animal is immediately below it.)

nesses it was necessary to add some illumination to the deep side. The procedure for each type of apparatus and each experiment was to try to balance the brightnesses so as to make them as nearly equal as possible. The ordinary brightness readings for each apparatus have been indicated in the apparatus section. But brightnesses were not always *exactly* equal, particularly for ^{apparatus} apparatus like the large visual cliff (Model III) which was influenced by variations in daylight illumination. What is the effect of an artificial manipulation of brightnesses?

Extra illumination was added to the deep side of the standard setup (Model II) so that the Weston Master III reading was 0.8 on the shallow side and 6.5 on the deep side. The deep side was 10" in depth and the $\frac{3}{4}$ " checkered pattern was used. Results appear as Condition G in Table 4. Ten hooded subjects were used and all 10 (100%) descended on the shallow side. The original apparatus had slightly greater brightness on the shallow side (1.6 reading) as compared to the deep side (1.4 reading).

It seems clear that a small variation in brightness has no influence on the behavior observed in this apparatus, since the preference for the shallow side existed despite added brightness on either side.

Reflection Control

Although the controls first described seemed to meet any criticism which occurred to the authors, it was decided to make a further effort to eliminate reflections from the glass. It might conceivably be argued that the reflections were unequal on the two sides since one was lighted only from above and one from both below and above. If all the light came from below in both cases, there should be no reflections at all. The lighting was therefore rearranged as follows. Two 17" fluorescent bulbs (15-watt, 1" diameter) were placed under and along the center board, parallel to one another. The textured surface on the shallow side was lowered to 2" below the glass, so that its illumination came from the fluorescent bulb on its side. The textured surface on the deep side was on the floor, 10" below the glass, as before and was illuminated by the fluorescent bulb on its side. No other illumination was used.

A new center board, wider than before, was introduced in order to cover completely the lights below. It was covered with the same patterned material used for the textured surfaces. It was only $1\frac{1}{2}$ " high (above the glass), since the shallow surface was 2" below the glass. This meant that the depth from the top of the board to the textured surface was $3\frac{1}{2}$ " on the shallow side and $11\frac{1}{2}$ " on the deep side. The fact that the board was only $1\frac{1}{2}$ " above the glass meant that the animals could touch the glass without coming down—i.e., could feel an equivalent surface on both sides. This tactual cue was unavoidable with the

lighting coming from below, since the surface was already 2" below the glass and a greater height might inhibit the animals from descending on the shallow side as well as the deep. Since the tactual cue worked against the result predicted if the animals responded to the visual depth cues, it could not prejudice the results in that direction. (It would have the effect of equalizing choices of the two sides.)

The underneath lighting was very effective in eliminating reflection; a human observer was not aware of the presence of the glass at all.

Twenty animals were run on this setup (Condition H in Table 4). Of these, 90% went to the shallow side, and 10% to the deep. The relative visual depth of the two sides was therefore effective in creating a preference with reflection eliminated, even with tactual cues available that worked for equality.

Threshold Determination

The fact that a 10" depth was just as effective as a 25" depth led us to wonder at what point the drop-off would cease to be effective. The objective of this experiment was a psychophysical curve showing the relationship between depth and descent behavior. Instead of the two-sided cliff, which makes the animal's choice a relative one, it was decided to use a one-sided cliff with graduated depths. The animal was placed on a board 4" above the glass; the textured surface was directly under the glass, or at varied depths below it. The rat was observed for 3 minutes and scored simply on descent or no descent.

Since previous animals, with the coarse ($\frac{3}{4}$ " checks) texture, had avoided the deep side almost 100% when the pattern was 10" below the glass, this depth was the greatest used. The other depths (below the glass) were 0, 2, 4, 6, and 8 inches. Since the animal was placed on a 4" board, the drop-off from his feet was actually 4, 6, 8, 10, 12, and 14 inches.

The board on which the animal was placed was covered with the same checked pattern as that on the surface below. The center board was inserted in the box just as it had been previously, but a back wall was provided so that the animal could look down on only one side.

The effect of the glass, as compared with a no-glass situation, was also tested in this experiment. Each of the six depth steps was tested with glass in the usual position and without the glass. Each animal was run twice in the experiment, once on the no-glass and once on the glass condition but with a different depth step on the two runs. There were 120 animals. Each step was therefore tested 40 times (40 different subjects), 20 times with the glass present and 20 without. These groups were further divided into first runs and second runs, so that first and second runs were represented equally at each step, and in the glass and

no-glass conditions. Time of day of running was also equated for the groups. Half the animals were males and half females. They were distributed equally through the groups.

Results. Table 5 shows the percentage of animals descending at each of the six depth steps. The combined (overall) percentage represents results on 40 animals for each step. There is an unbroken slope from zero depth (between glass and pattern) and the 10" depth. At zero depth 72.5% of the animals descended. Figure 7 shows the curve plotted from these percentages. It drops very steeply from zero depth to the 6" depth, where only 10% of the animals came down. This point seems comparable to a threshold, since there is a marked change in the slope of the curve here. Up to this point, however, the curve falls in a straight line: the steeper the drop-off, the fewer the descents.

Both the glass and the no-glass conditions yielded a steadily falling curve, showing percentage of descents to be a function of degree of depth. There is not much difference between the percentages for the two conditions. At those depth steps where the groups could be compared by chi square (they could not where any frequency was zero), two proved to be barely significantly different ($p < .05$ for both differences, without a correction), the 2" step and the 4" step. More animals descended when there was glass below them. This is not unreasonable for there are some cues provided

by the glass to indicate that it is a surface (e.g., reflections, echolocation).

A comparison of the first and second runs indicates a greater tendency to descend at five of the depth steps on the first run. The two runs were done on separate days, but despite this, the animals' exploratory drive appeared to have diminished. This trend was investigated further in another experiment. There was no consistent difference between males and females.

This experiment permits the conclusion that, for the hooded rat, the tendency to avoid a drop-off is a simple monotonic function of the degree of depth or steepness of the drop-off, up to a limit of no descent.

Effect of Repetition

Since the foregoing experiment appeared to indicate some diminution in number of descents on a second run, an experiment

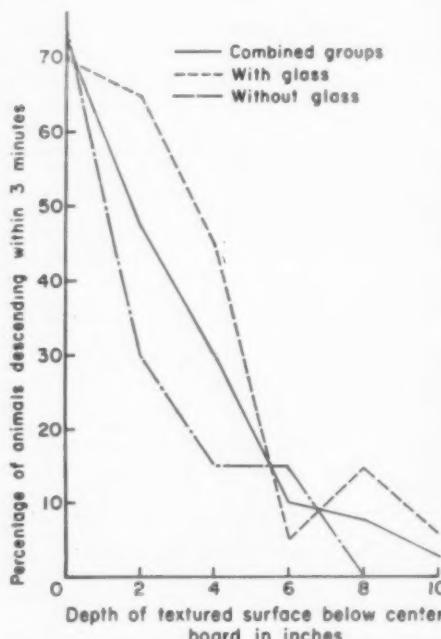


Fig. 7. Percentage of animals descending at each of six depth steps, with a one-sided cliff. (Animals were run at each depth with glass below the board, and without glass.)

TABLE 5
PERCENTAGE OF ANIMALS DESCENDING AT EACH DEPTH ACCORDING TO PRESENCE OR ABSENCE OF GLASS, FIRST OR SECOND RUN, SEX OF ANIMAL, AND WITH GROUPS COMBINED

Depth	0	2	4	6	8	10
Glass	70	65	45	5	15	5
No glass	75	30	15	15	0	0
First run	85	50	40	15	10	0
Second run	60	45	20	5	5	5
Males	70	35	45	0	15	5
Females	75	60	15	20	0	0
Combined groups	72.5	47.5	30	10	7.5	2.5

TABLE 6
PLACE OF DESCENT AND LATENCY AS A
FUNCTION OF REPEATED TRIALS
(N = 10)

	Day 1	Day 2	Day 3	Day 4	Day 5
Percentage to deep	0	10	0	0	0
Percentage to shallow	100	90	70	60	40
No descent	0	0	30	40	60
Mean latency in seconds	9.1	48.9	72.9	98.2	138.3

was designed to test the effect of repetition. The double cliff (Model II) was used, with a coarse pattern and a depth of 10" on the deep side. Subjects were 5 male and 5 female adult hooded rats. Each was run once daily for 5 days. Time and place of descent were recorded. The animal was removed at the end of 3 minutes and "no descent" recorded, if it remained on the board continuously.

Table 6 shows clearly that there is no trend toward exploring the deep side as trials are repeated. But there is a tendency for the animals to remain longer on the center board—to go nowhere. Latencies increased consistently, as did number of no descents.

Depth discrimination shows no change as trials are increased. The result of repetition in this species is extinction of a general tendency to explore and hence to descend from the center board.

COMPARATIVE EXPERIMENTS

The visual cliff was designed to permit comparison of the behavior of different species and ages of animals in depth discrimination. While some alterations had to be made in adapting the apparatus for some species, a common visual stimulus was present, and the same procedure was used for all. The slight alterations themselves are informative and will be taken up as each species is discussed. Depth discrimination of the following animals was observed: rats

(hooded and albino, infant and adult), chickens (the chick and the adult chicken), turtles, lambs, kids, pigs, dogs, cats, monkeys, and human infants. This section will discuss the general depth discrimination of each species, including relevant observations of behavior. The manipulation of experimental variables will be taken up in other sections.

Hooded Rats

The ability of the adult hooded rat to discriminate depth has already been described in the section on basic experiments. This section will describe the behavior of the infant hooded animal and take up observations of the behavior of the rat that are relevant to species comparisons and to replication of these experiments by others.

The infant hooded rat (27-30 days old) discriminates depth approximately as well as the adult hooded rat. The data are presented in Table 7. Of 34 subjects run on the standard height conditions, only two came down on the deep side. The infant rats showed, on the other hand, a marked preference for that side when a textured pattern was put directly under the glass there (the "zero-inch" condition). The animal's descent in this case was away from the experimenters. The cliff was avoided, then, by the experimental group, despite a tendency for animals to go in the opposite direction in the control situation.

The latency data for adult or infant hooded rats show characteristic behavior for this species. Subjects rarely descended from the center board with a latency of more than 1 minute, and less than 1% descended with latencies of more than 2 minutes. Observation periods at first were 5 minutes but were cut to 3 minutes.

The height of the center board is critical for the rat. An experiment with young rats will illustrate this point. In the experiment with the fine texture and 25" height reported in Table 7, the board was set at 2 $\frac{1}{2}$ " for these young animals. Of the 14 animals that descended from the board, one came down on the deep side and only 3 crossed to another side during the 3-minute obser-

TABLE 7
BEHAVIOR OF INFANT HOODED RATS 27-30 DAYS OLD ON THE VISUAL CLIFF

Condition	Age (days)	N	Shallow side		Deep side		% no descents
			% descents	Median latency (seconds)	% descents	Median latency (seconds)	
Small pattern 53" deep side	26-27	14	93	23	0		7
Small pattern 0" both sides	26-27	16	19	23	75	17	6
Fine texture 25" deep side	28-40	18	72	25	6	2	22
Coarse texture 10" deep side	32-33	22	77	29.5	5	8	18
Coarse texture 0" both sides	25-27	27	30	14.5	52	9.5	18

vation period. A prior experiment had been performed with 9 hooded subjects 28 days old and a 1½" board. Here, 6 descended on the shallow side and 3 on the deep side and 8 of the 9 subjects crossed the board to the other side. The median latency at the 2½" height is 25 seconds and at 1½" it is 3 seconds. Both the tendency to cross and the latency differences are significantly different ($p < .05$). This experiment shows that, for the rat, the board must be high enough to induce some disinclination to jump down so that predominantly visual cues will be used for descent; otherwise this animal will tend to respond on the basis of tactual and kinesthetic cues.

However, with a given height of the center board, an increased drop to the floor below may strengthen avoidance of the cliff. At the 53" depth a 1½" board was used and 93% of the infant rats descended to the shallow side, none to the deep. Only 1 of 13 subjects crossed to the deep side. But at the 25" depth with an identical 1½" board, 67% went to the shallow side and 8 of 9 crossed to the deep side. Thus the low board elicited more crossing behavior at the 25" depth than at the 53" depth ($p < .01$), and a weaker preference for the shallow side.

The experiments in Table 7 at a 10" depth used a 3" board which was lowered to 2½" if the young animal did not descend in 3 minutes. Under these conditions almost all subjects came down to the shallow side and few crossed.

In summary, the hooded rat, infant or adult, has effective visual depth discrimination but to demonstrate its maximum acuteness, the animal must be prevented from using tactual cues by manipulating the height of the center board from which it descends.

Albino Rats

It is generally considered that the vision of the albino rat is poorer than that of the hooded rat. But how does this affect depth discrimination? With adequate visual cues depth discrimination of albinos and hooded might be equivalent. Using the Model II apparatus with the ¾" squares and the deep side 10" below, 94% of 16 adult albino animals descended to the shallow side, 6% to the deep side. No animal crossed the center board to the deep side, behavior indistinguishable from that of the hooded rats in this setup.

Infant albino subjects were also tested on the original apparatus (Model I) at the 53" height with a 1½" board and observed for 5 minutes. These results are shown in Table 8. While the difference between controls and experimentals is not significant, the results are in the expected direction and, though the albinos look poorer in depth discrimination, the difference between the albino subjects and the hooded subjects in Table 7 is not significant. Whether the large percentage of no descents among the litter mates of the control animals is due to the

TABLE 8
BEHAVIOR OF INFANT ALBINO RATS 26-29 DAYS OLD ON THE VISUAL CLIFF MODEL I

Group	N	Shallow side		Deep side		% no descent
		% descents	Median latency (seconds)	% descents	Median latency (seconds)	
Experimental	17	41	67	18	23	
Control	14	29	42	71	12	41

depth situation is difficult to determine, though it is a significant difference. The tendency is for latencies of descents toward the experimenters (the shallow side) to be higher than those toward the deep side, away from the experimenters. The experimental animals may have stayed on the center board rather than descend to the shallow side, toward the experimenters.

The most general statement that can be made from these data about the albino rat is that with adequate visual stimulation the behavior is similar to that of the hooded animal.

Baby Chicks and Adult Chickens

The baby chick is an interesting animal to use on the visual cliff because it can be tested within a few hours of birth; there is little possibility of learning to avoid depth

if depth discrimination is effective so soon. The chick is a more visual animal than the rat; it has no vibrissae that give information about the environment ahead or forepaws for exploring it. The animal jumps down from a pedestal, committing itself to a depth decision based on optical stimulation alone, within a few minutes after hatching. The rat, as has been pointed out, will only jump after prolonged training, though it will *descend*, forepaws first, feeling its way as it looks, without pretraining.

The first experiment with baby chicks used the cliff Model II with a fine pattern and the height set at 25" above the floor. Fifty-seven baby chicks 2-4 days old were placed on the central board, 1½" high, and observed for 3 minutes. As Table 9 shows, only 13 came down from the board, but all descents were to the shallow side. The second experiment used 1-day-old chicks on

TABLE 9
BEHAVIOR OF BABY CHICKS ON CLIFF MODEL II

Condition	N	Shallow side		Deep side		% no descent
		% descents	Median latency (seconds)	% descents	Median latency (seconds)	
Fine pattern 25"	57	23	80	0	—	77
Red checks 10"	27	74	297	0	—	26

Note.—The observation period was 3 minutes for the "fine pattern" group, but was extended to 10 minutes for the "red checks" group.

the same apparatus with the red $\frac{1}{4}$ " checks and the height of the deep side 10" above the floor. For this experiment, the subjects were observed for a maximum of 10 minutes and 20 of 27 descended to the shallow side, 7 staying on the board for 10 minutes. No chick in either experiment descended to the deep side. That so few chicks came down from the center board in the first experiment can probably be attributed to the short observation interval used. While 23% of the subjects used in the first experiment came off the board in the 3-minute period, only 19%, a comparable number, descended in the first 3 minutes in the second one, but with a longer observation time, most of the subjects eventually jumped off the board. The average chick placed on the board remains motionless for some period of time, then begins to cheep and move its head from side to side and finally jumps off the board with little of the locomotion up and down the center board so characteristic of the rat.

The present experiments, thus, have used a different technique than Thorndike used with 4-day-old chicks to demonstrate, as he did, excellent depth discrimination in the day-old chick.

Adult chickens were tested on the large version of the visual cliff (Model III). A total of 50 adult chickens were used, 30 white Leghorns and 20 Rhode Island Red-Barred Plymouth Rock crossbreed chickens.⁷ The chickens had been used as subjects in a T maze experiment; they were accustomed to being handled and they were on a deprivation schedule. Initial, pilot observations were with satiated chickens but these subjects all remained on the board for the entire 5-minute period. To motivate the hungry subjects, a very small quantity of cracked corn was scattered along the center board in front of it. Usually the chickens ate this immediately. All subjects were observed for 5 minutes. The criterion response was complete descent from the board with both feet on one side of the center board.

⁷ The assistance of Herbert L. Pick, Jr. in this experiment is gratefully acknowledged. He both supplied the subjects and helped run the experiment.

The results, shown in Table 10, demonstrate that the initial descent of the chickens was predominantly to the shallow side, but three animals first went to the deep side. Since the experiment lasted 5 minutes for each subject, some subjects walked back up on the board and came down again. Later behavior of the chickens can be divided as follows: 17 (41%) remained on the shallow side, 13 (32%) went up on the board but later descents were only to the shallow side, in later descents 7 (17%) walked across the deep side, 4 (10%) later flew across the deep side and landed on the glass. In addition 3 animals flew across the deep side and hit the glass when the experimenters tried to catch them at the end of the experimental session. No subjects flew from the center board toward the shallow side.

To help describe the behavior of the adult chickens, the written protocols of the first six subjects run are included below:

S₁. Latency—5 minutes. Would not move until corn put on board, ate corn, went twice to shallow side, would not go to deep, at end *leaped and flew* toward deep side, hit glass, crouched. (Corn put on center board for all subsequent subjects.)

S₂. Latency—1:30. Ate corn on board then went to shallow side, back to board, then to shallow, back to board where feet put slightly on deep, then flew to perch on side board at deep near pinwheel (had walked around shallow side as far as pinwheel several times).

S₃. Latency—0:45. Off on shallow, stayed.

S₄. Latency—0:15. Off on shallow side three times from board; at end of session experimenter tried to get subject and it flew across toward deep side, landed on glass near pinwheel.

S₅. Latency—0:30. Off on shallow, stayed on shallow.

TABLE 10
BEHAVIOR OF ADULT CHICKENS ON LARGE
VISUAL CLIFF MODEL III

N	Shallow side		Deep side		% no descent
	% de- scents	Median latency	% de- scents	Median latency	
50	76	0.62	6	2.00	18

S. Latency—0:10. Off on shallow three times then walked across deep; would not peck at grain on deep side.

In general, the adult chickens markedly preferred the shallow side. Subjects on the center board often flapped their wings when looking over the edge of the board down toward the deep side. They frequently flew toward the deep side but some subjects also walked across it, usually with a peculiar high stepping gait and some wing flapping. The chicken is an animal with good depth discrimination, as is shown in the initial descent behavior, but wings offer protection from harm at heights as low as those used in this experiment.

Kids, Lambs, and Pigs

The goat and the sheep are interesting animals for studying depth discrimination, since they are descended (the goat in particular) from mountain climbing ancestors. When they are born they walk immediately, like the chick. A total of 16 kids and 20 lambs were used, their ages varying from 24 hours to 77 days old. Animals were borrowed from the Cornell Behavior Farm for this experiment.⁸ First observations were carried out in Morrill Hall at Cornell

on the large visual cliff with a 1" high board, on five infant goats 6-7 days old. All animals walked off the center board to the shallow side on each trial (two trials per subject). The subjects avoided the cliff side and would not approach it. They preferred to look at the floor over the edge of the shallow side where the side board offered support in preference to being too close to the center board. The subjects were also placed successively on the glass on either side (a textured surface directly under them on one side and 40" below on the other). The behavior of the animals was highly stereotyped. When placed on the shallow side they walked forward immediately. When placed on the glass of the deep side an immediate backing response was observed, the animals' front limbs became rigid and the hind limbs pushed backward. If the animal was forcibly pushed by the experimenter across the glass, the front limbs remained rigid until the head was over the center board, the front limbs 2" to 6" away from it. At this point, the animal suddenly leaped forward on to the center board and across to the shallow side. The complete protocols of these five animals are reproduced below:

S. Abel, male, born January 31, 1959. Placed on board at east end of room, off on shallow at 45 seconds, walked around on shallow. On board from west side, off on shallow at 4 seconds (off on shallow means with all 4 feet). Walked around on shallow for about 5 minutes. Put in middle of glass on deep side. Backed up until reached side board. Put in middle of glass on shallow side. Walked forward after about 5 seconds.

S. Aaron, male, born January 31, 1959. On board from east side, off on shallow at 10 seconds, walked around. On board from west side, off on shallow at 3 seconds, walked around. Put in middle of glass on deep side. Backed up immediately until got to side board, experimenter pushed toward center board, resisted, fell on forelimbs. When 2" from center board suddenly, as if released from a taut spring, got up on center board and walked off on shallow.

S. Carl, male, born February 1, 1959. (This subject had weak right hind leg.) Put on board from west side. Off on shallow 50 seconds, walked around. Put on board from east side. Off on shallow 35 seconds, walked around on shallow. Put in middle of deep, backed up until reached board at edge. Put in middle of shallow, went forward after some teetering on weak legs.



—William Vandivert

Fig. 8. Young goat being tested on visual cliff, Model III.

S₄ Cora, female, born February 1, 1959. On board at west side, off on shallow at 42 seconds. On board at east side, off on shallow at 41 seconds. Put in middle of shallow, went forward immediately. Put in middle of deep, moved backward immediately against side of apparatus.

S₅ Mac, male, born January 30, 1959. Put on at east, off on shallow at 7 seconds. Put on at west, off on shallow at 2 seconds. Put in middle of glass on shallow side, walked forward immediately. Put in middle of glass on deep side, froze, stayed there 30-40 seconds (put very close to center board, forelimbs about 6" away), jerky movement forward, reached center board and leaped up on board and over on shallow side.

After this experiment the large cliff was taken to the Cornell Behavior Farm and subsequent observation made there. The shallow side and the center board were covered with the $\frac{1}{4}$ " checked squares and the checked squares were also laid over the concrete floor. Twenty lambs were used. All went immediately to the shallow side. Ages of the lambs ranged from 24 hours to 65 days. Later, an 11 additional kids, aged 15-77 days, behaved similarly to the first five kids used. All went to the shallow side. No animal ever spontaneously walked across the glass of the deep side.

Besharat, Wiley, and Moore covered a large piece of plywood with the checkered pattern. If the plywood was placed under the glass of the deep side the subjects, lambs or kids, would walk around on it. If the board was dropped the animal immediately froze and backed up. Lambs, which bleated frequently during the experiment, stopped bleating when visual support was removed. They remained motionless and trembling on the surface of the glass. The kids, on the other hand, were much more lively. They seldom bleated, they were more exploratory at the shallow side and, though they backed up, they kept moving on the deep side. The behavior with the "optical floor" is so stereotyped in these species that simply by raising or lowering the board under the animal its behavior can be converted from free locomotion to rigid immobility. This was demonstrated many times in a short observation session and within the limits used (8 to 10 raisings and lowerings of the board) there was no extinction.

Two pigs, 6 weeks old, were also put on the central board and they immediately ran to the shallow side. Over the void they became rigid, behavior more similar to the lamb than that of the goat.

The completely predictable, stereotyped, behavior of these animals fits well with a theory of evolution. The ungulates are generally large hooved animals with spindly legs. Most of them can move their bodies rapidly across the surface of the land, but any slight misstep (a hole in the ground, the edge of a cliff) will throw too much weight on the slight supporting limbs, breaking them. For such an animal, herbivorous but often preyed upon by carnivores, accurate and immediate depth discrimination and discrimination of the existence and state of the substratum is mandatory for survival. The species tested not only have evolved accurate depth perception but also a protective adaptive response that immediately stiffens the forelimbs and backs the animal away from a drop-off. This protective adaptive response to a potential drop-off is so primitive that when the kid, for example, is shocked with electricity in the forelimb the same response is obtained (see Gibson, 1952).

Turtles

The aquatic turtle was tested by Yerkes (1904) and found to have poorer depth discrimination than the land forms. An aquatic animal is interesting to observe on the visual cliff, not only for depth discrimination but also to determine the role of the glass. Perhaps the glass surface would appear like water and attract more descents to the deeper side, or the responses might be equally divided between the two sides because of the inadequate depth discrimination of this species. The turtle selected for this experiment was *Pseudemys scripta elegans*, a turtle inhabiting ponds and spending time on land only for nesting or migration.

The turtles were placed on the large visual cliff at one end and observed until they crawled off the board onto the glass. They were then picked up, usually after they had crawled 4-5' over the glass, and replaced on

the opposite end of the board. A total of 6 trials was given for each animal, if possible. Because the animals often did not move in 15 to 20 minutes, all trials were not necessarily given in one session but, where necessary, spread out over several days. Even so, not all animals came off the center board six times, but all animals except one had at least four trials. This turtle spent several hours on the visual cliff without moving. The results are shown in Table 11. Eight out of 10 of the turtles first went to the shallow side of the apparatus and subsequent trials still showed a marked preference for the shallow side. Three turtles showed perfect discrimination, three went five out of six times to the shallow side, three showed no preference or a tendency to go most frequently to the deep side, and one animal, with only one trial, is inconclusive. When the turtle does come down on the deep side it behaves the same way that it does on the shallow side. It crawls slowly forward and does not look down. However, many subjects started toward the cliff side, paused, and turned around to go off the board on the shallow side.

In summary, the aquatic turtle tested here showed discrimination of depth, supporting

the observations of Yerkes, but its depth discrimination was not as marked as that of other species tested, such as the goat. In fact, depth discrimination in aquatic turtles was the poorest of any species studied so far.

Cats

That a cat has good discrimination of visual depth seems almost self-evident, in view of its ability to pounce at and seize prey, and to perform such skilled visual-motor coordinations as walking along a fence top. But very little, if anything, is known about the development of such discriminative ability. The visual cliff seemed to present an excellent means of testing a kitten's ability to discriminate differences in depth as early as locomotion was possible.

Our first attempt to study behavior of kittens on the visual cliff was a failure, since the kittens were tried immediately after the eyes had opened (about 10 days) and proved unable to locomote with any control at all of motor coordination. They fell backward or lay on the center board and mewed. The falls occurred because the center board was too narrow.

TABLE 11
BEHAVIOR OF TURTLES ON LARGE VISUAL CLIFF

Turtle	Place of first descent	Shallow side		Deep side	
		Number of descents	Median latency (seconds)	Number of descents	Median latency (seconds)
1	shallow	6	180	0	
2	deep	2	30	4	28
3	shallow	1	900	0	
4	shallow	6	180	0	
5	shallow	5	35	1	20
6	shallow	6	145	0	
7	shallow	5	40	1	240
8	deep	2	180	2	135
9	shallow	1	120	3	300
10	shallow	5	90	1	150
Total		39		12	

The second attempt to test cats was planned with knowledge of the earlier mistakes. It was decided to test the cats only after the visual placing response had matured, and to observe them on the large cliff with a center board 9" wide. The height of the center board was raised or lowered as the size of the kitten required. Two litters of kittens were observed, each six times, for a 2-minute interval. All the trials took place the same day. The first litter was obtained from a farm. The kittens were at least a month old and rather wild, since they had lived in a barn and had never been petted. The second litter was brought to the laboratory when the kittens were 10 days old and was reared thereafter in the laboratory. These kittens were very tame. They were tested when they were 27 days old.

Table 12 presents the results for these two litters of kittens. Half the first litter was tested with a 1" center board. This board proved to be much too low, since these kittens were very agile and easily touched the glass surface in all directions, leaning far out without falling. For the other four kittens, the board was raised to 8". They could not touch the glass, but it was an easy jump for them. The visual placing response was present in every kitten.

The first four kittens (with a 1" center board) walked to the shallow side 79% of the time, and to the deep side 21% of the time. None of them remained on the board. The second four kittens (with an 8" center board) jumped 67% of the time to the shal-

low side, 4% (only once) to the deep side, and 29% of the time did not descend in the 2-minute interval. The kitten which went to the deep side appeared to be attempting to escape from the experimenters.

The second litter of six kittens was all run with a 2½" board when the kittens were 27 days old. They were smaller than the other kittens, but had good motor coordination. All of them had a well-developed visual placing response. They went 86% of the time to the shallow side and never to the deep side. There was no descent 14% of the time.

The behavior of the cats on the glass of the shallow side was confident and normal. They walked or ran about, especially the first litter of rather wild kittens, which ran

TABLE 12
BEHAVIOR OF LIGHT-READED KITTENS ON LARGE
VISUAL CLIFF

Kittens	S	Times to shallow	Times to deep	No descent
Barn, 1 month old, 1" board	1 2 3 4	6 3 4 6	0 3 2 0	0 0 0 0
%		79	21	0
Barn, 1 month old, 8" board	5 6 7 8	5 5 2 4	0 1 0 0	1 0 4 2
%		67	4	29
Tame, 27 days old, 2½" board	1 2 3 4 5 6	6 5 6 6 3 5	0 0 0 0 0 0	0 1 0 0 3 1
%		86	0	14

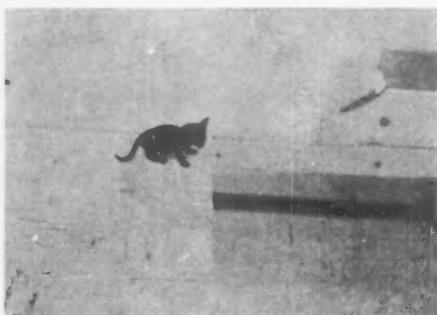


Fig. 9. A kitten looking over edge of cliff, Model III.

Note.—Each kitten was tested six times for 2-minute intervals.

from the experimenters when an attempt was made to remove them. The kittens were each placed, after the experiment, on the clear glass of the deep side. The behavior here was a great contrast to the walking and running about on the shallow side. The kittens backed up, looking constantly downward. The backing was frequently round and round in a circle, since the kitten was looking downward and could not see where it was going. Sometimes it succeeded in backing to the wall; then it proceeded to creep around the edge, hugging the wall, and walked on what appeared to be a small path below the glass made by the supporting board. One kitten backed to the wall, climbed the edge and clung to it. None of these kittens walked forward on the clear glass of the deep side, as they had on the other side. This behavior was sometimes accompanied by shivering and mewing.

That there was a strong preference for the shallow side is evidenced by the trials for the individual cats, as well. No cat ever went more often to the deep side. One cat, the wildest, went an equal number of times to the two sides. It also jumped from the table side to the floor when the experimenters tried to catch it.

The data as a whole permit the conclusion that a young cat of 27 days, when reared normally, has developed a good discrimination of depth and avoids a deep visual drop-off.

Dogs

A dachshund puppy and a litter of cocker spaniels were tested on the large visual cliff. The dachshund puppy was put on the center board, raised to a height of 2½", and observed for 2-minute intervals with the dog's owner standing alternately at the far end of either side. The puppy had been petted a good deal. It rushed to its owner when he stood at the shallow side, and cried and whimpered when he stood at the other side. It never crossed to him over the glass of the deep side.

The cocker spaniel puppies, a litter of six, were tested at 7 weeks of age. The center

board was raised to a height of 2½" and each animal was placed six times on the center board. After this period of testing each animal was placed successively on the deep and the shallow side, twice on each side, and observed. The results are shown in Table 13. No puppy chose the deep side for descent from the center board. The overall median latency for descent was 6 seconds and the median latencies for individual puppies ranged from 3 to 20 seconds. When placed on the shallow side the puppies walked forward; on the deep side, they usually remained motionless for a period of time and then backed up. Two of the puppies visibly trembled when placed on the deep side and another one squealed, behavior not observed on the shallow side. These protocols are also reproduced in Table 13. In the case of the two animals that trembled when placed on the deep side, a piece of masonite was raised from below and put right under the glass. The puppies immediately walked forward.

The data, thus, show that these dogs had excellent discrimination of depth.

Monkeys

Two infant rhesus monkeys⁹ were observed several times on the large cliff (Model III). The cliff happened to be arranged so as to equate density of texture for the two sides (see later experiments). Motion parallax, and, for the monkeys, probably binocular parallax were available as cues. One (male) was observed at 10 days, at 18 days, and at 1½ months. At 10 days, this animal (Albert), left the center board at once and scampered around the shallow side. When placed on the board a second time, with arms placed by the experimenter on the glass of the deep side, he went to the wall at the edge and followed it round the deep side, coming back to the center board. Put on again, he crossed over the glass of the deep side to the wall. The manner of locomotion was different from that on the shallow side, for he crawled with stomach

⁹ Made available through the courtesy of Robert Zimmerman.

close to the glass and looked down constantly. When he reached the wall, he clung to it. A blanket was placed on the glass at the far edge of each side as a lure.

At 18 days, his bottle was used as a lure, first on one side and then on the other for a number of trials. At this time, he went consistently to the bottle at the shallow side, but always refused to cross the glass over the deep side. Other testing during the interval between 10 and 18 days showed that his form discrimination had developed markedly during the time. The behavior on the cliff had changed greatly since the trial at 10 days and showed a clear distinction between the two sides.

At 1½ months, Albert became very emotional when placed on the cliff. He hugged his legs, head down on the board, and refused at length to move. He finally leapt to

his blanket when it was waved at him on the shallow side, but refused to reach for it on the other side.

The other monkey, a female (Maya) was observed first at 12 days. She seemed immature in both motor and perceptual ability. She crawled to the shallow side, and was also coaxed eventually onto the deep side. Her gait differed; she dragged her hind legs and looked down constantly on the deep side.

Maya was observed again at 35 days. She consistently went over the shallow side for her blanket but refused over and over to cross the deep side for it. Several times she retreated to the shallow side, even though the blanket was being proffered from the other side.

She was placed finally on the glass over the deep side. She lay prone, arms and legs

TABLE 13
BEHAVIOR OF COCKER SPANIEL PUPPIES ON LARGE VISUAL CLIFF

<i>S</i>	Times to shallow	Times to deep	No descent	Behavior on shallow side	Behavior on deep side
1	6	0	0	(1) walked forward (2) walked forward	(1) sat up for 20 seconds then backed up (2) sat up for 40 seconds then two steps forward, then backed up, then walked forward to center board
2	5	0	1	(1) walked forward (2) walked forward	(1) lay down, after 10 seconds started to tremble, experiment stopped after 1 minute (2) lay down 30 seconds then started to tremble
3	6	0	0	(1) walked forward and then lay down (2) walked forward and then lay down	(1) sat still for 40 seconds then backed up (2) lay down for 40 seconds then backed up
4	6	0	0	(1) walked forward slowly (2) walked forward slowly	(1) lay down, after 1 minute started to tremble (2) lay down and whimpered
5	6	0	0	(1) walked forward (2) walked forward	(1) sat still upright for 8 seconds then squealed and backed up (2) sat still upright for 20 seconds then backed up
6	6	0	0	(1) walked forward (2) walked forward	(1) sat still upright for 20 seconds then backed up (2) sat upright for 20 seconds then backed up
%	97	0	3		

curved out at the sides, and looking downward, much as if she were clinging to a tree branch.

Both these monkeys appeared to have matured in depth discrimination between the first and second tests. Thus, locomotion appeared to precede by a week or so good depth discrimination in these animals. In its natural environment, the monkey would be carried by its mother during this period.

Human Infants

After the large visual cliff was first constructed, and a 50-pound weight had been placed on the glass to make sure it was safe for infants, an 18-month-old male infant, who had been walking since he was 10 months old, was placed on the center board. He crawled off the center board to the shallow side and stood up. He could not be persuaded to walk across the glass of the deep side, but he was then picked up, placed on the glass of the deep side, and coaxed toward the center board. He firmly clutched the wooden support with one hand, curled his toes and hitched himself cautiously toward the experimenter. When he reached the center board he crawled up on it and ran over the glass of the shallow side.

But this child was 18 months old, and had fallen, according to his parents, from cribs, beds, sofas, chairs, etc., on to the hard floor or the bare ground. Would children who had just learned to crawl behave similarly to this child? Or had this child learned caution from falling? The following report describes the testing of 36 infants, 6-14 months old, that were crawling, according to their mothers.

The first infants were placed on the center board and observed for several minutes, a procedure that had worked well with animals. The mother was placed behind a screen where the child could not see her. A toy (red, white, and blue pinwheel) was placed at the end of both sides. It rotated slowly and emitted a tinkling sound as it turned. The protocols of the two subjects tested with this procedure follow:

S₁. Girl, 9 months old. Looked a number of times to both sides and at both pinwheels, touched

shallow side but wouldn't go either way. (Mother behind screen. Total testing time 8 minutes.)

S₂. Girl, 6 months old. Looked mostly at experimenter, a little at pinwheels; crawled half-way across board, slipped on shallow side, back to board, then off on shallow again, near experimenter at west side of room by now, cries and is picked up by experimenter; put face down to glass on deep side during testing, peered under. (Mother behind screen. Testing time 7 minutes.)

The third subject marked a change in procedure. After the infant would not move the mother was put at the shallow side. She turned the pinwheel and talked to the child. The protocol follows:

S₃. Male, 10½ months old. (Mother at shallow side, experimenter at deep side.)—child cries a little; at 4 minutes 50 seconds from time of first starting testing gets off board toward mother, goes to lure, touches it. (Mother at deep side, experimenter at shallow side.)—cries when put back on board; knee on shallow side toward experimenter but won't go farther, cries.

The standardized procedure evolved was as follows: The mother stood twice at each side, alternating, some mothers starting at the shallow side, some at the deep. The mother stood for 2 minutes at each side unless the child got off the board and reached a lure. If this happened, the child was put back on the board and the mother switched sides. An experimenter stood at each end of the board so as not to influence the way the infant crawled. If the child crawled away from the mother the experimenter went toward the infant to safeguard him.

The use of this standardized procedure clearly showed that the babies discriminated depth. They crawled toward the mother when she stood at the shallow side and refused to cross the glass to her when she stood at the deep side. Many infants crawled to the shallow side when the mother stood at the deep side twirling the pinwheel and urging him to come to her. Eleven subjects did this; no subject crawled away from the mother across the deep side when she stood at the shallow. Some of the babies cried when the mother stood at the deep side and would not go to her. In such cases, the 2-minute observation period from the deep side was usually terminated at 1 minute.

Once the procedure was standardized, from Subject 10 on, the infants tended to



—William Vandvert

Fig. 10. This mother has just placed her child on the center board in preparation for testing the infant.

behave very consistently. They crawled to the shallow side twice; in only two cases did the child go but once to the shallow side. The three negative cases, all boy infants, were also consistent; each child crawled twice to the mother across the deep side, twice to her at the shallow side.

When 30 subjects had been run, there were five subjects in the youngest (6-7 month) age group. Of these infants, three had not moved from the center board, one had gone to the shallow side only and one to both sides. Even though two cases is not a large sample, one of the two had crawled across the deep side and it seemed possible, a trend that had to be checked, that very young infants could not discriminate depth as adequately as older ones. Consequently, telephone calls were made to mothers in the city with infants 6-7½ months old. Very few of these infants were crawling, but five

subjects were added to the youngest group. Of these five children, two remained on the center board and three crawled only to the shallow side. The indication was, therefore, that younger infants have as adequate depth perception, if they can be tested, as the older ones.

The results on the first 36 subjects run are shown in Table 14. The only age trend is the inadequate locomotor ability of the younger subjects. They evidently crawled at home but not in a strange place. One must recognize that Table 14 is not a random sample of babies at the indicated ages, but a sample of infants whose mothers say they crawl. It is probably slightly skewed toward younger developers in the 6-7 months old group.

There is much interesting behavior to be observed in this situation. The babies were attracted by the lure and when they reached it, played with it eagerly. They peered down through the glass, sometimes patted it or leaned on it with their faces, yet refused to cross. Some used the deep side for support with one knee, others *backed* partly out across it (in first locomotion in the human infant the child often goes in reverse when he means to go forward), yet they still refused to cross. It was as if the infant could not recognize the consequences of his own actions, since he had already been where he now refused to go. The attitudes of the

TABLE 14
BEHAVIOR OF HUMAN INFANTS ON THE
VISUAL CLIFF

Response of S	Age of infant (months)				Total	%
	6-7	8-9	10-11	12-14		
Did not move off center board	5	2	1	1	9	25
To shallow side only	4	7	8	5	24	67
To deep side only	0	0	0	0	0	0
To both sides	1	1	1	0	3	8
Total	10	10	10	6	36	100

mothers were interesting as well. The predominant impression among mothers seemed to be that the child had failed the "test" because he did not have enough sense to realize the glass was safe to crawl over. The glass on the deep side was banged with hands and fists; cigarette boxes, lipsticks, purses, crumpled bits of paper, and other releasers of infant approach behavior were proffered—but the babies still refused to go across the glass of the deep side.

Reproduced below are two protocols from the experiment. The first one illustrates the youngest negative case, and the second the normal behavior of an older infant.

S₁₁, Male, 6½ months. (Mother at shallow.)—baby looks at both lures, turns toward mother and crawls to her after 60 seconds. (Mother at deep.)—turns to her at 15 seconds, starts to her at 20 seconds, and gets there in 50 seconds. (Mother at shallow.)—goes to her at once, gets there in 15 seconds. (Mother at deep.)—baby

starts toward shallow side; mother goes toward him; he goes back toward her, reaches her at deep in 60 seconds; then looks down through glass and starts back to center board.

S₃₀, Male, 11 months. (Mother at deep.)—he looks both ways at and experimenter; whimpers; looks other way, whimpers (2 minutes). (Mother at shallow.)—goes instantly to shallow side. (Mother at deep.)—baby goes other way (to shallow) at once, cries, starts toward mother, cries. (Experiment terminated here at 1 minute.) (Mother at shallow.)—gets to mother in 3 seconds.

These data show that the average human infant discriminates depth as soon as it can crawl. By the time that locomotion is adequate, which is the time when depth discrimination is necessary for survival, the infant can discriminate depth. In this the human infant fits with other late maturing species we have studied, the rat and the cat. But the human infant does not have quite the same marked apprehension of depth as the goat or the sheep, and a few crawled across the deep side. One also notes the relative clumsiness of the human infant at this age. Despite adequate depth discrimination many babies would have fallen but for the glass on the deep side to protect them.

But there is no evidence from these data that apprehension of height is learned from prior experience with falling. The avoidance and apprehension of height seems in general to be present as soon as an infant has adequate locomotion.

Conclusion

Comparative studies of depth discrimination on the cliff revealed that all the animals studied (hooded and albino rats, chickens, goats, lambs, pigs, dogs, turtles, cats, monkeys, and human infants) have some capacity for discriminating depth by visual cues alone. The relative excellence of the ability cannot be evaluated with great accuracy, but there was evidence that the turtles studied were inferior to the other species. The albino rat gave some (but only slight) evidence of poorer discrimination than the hooded.

The remarkable fact, indeed, is that animals with such widely differing eyes—a



Fig. 11. A mother calls to her infant from the deep side of the apparatus, but he refuses to cross to her. (Reproduced from *Scientific American* by permission)

panoramic ocular system in the case of goats and sheep, for instance—show similar behavior in this one respect. The human and the monkey infants, though better able to utilize binocular cues, were certainly not superior to the other young animals tested, some of whom (the chick and the goat, for instance) exhibited highly discriminative behavior a few hours after birth.

The ecology and "habits" of a species obviously must be considered in interpreting the developmental differences between species. The monkey and the human infant are normally carried by their mothers for a considerable time before locomotion is independent. That maturation of perceptual abilities should parallel this "plan" is hardly surprising. The cat, which is ordinarily hidden in a dark place by its mother for some weeks, is also a relatively late maturer; but the ungulates must be ready to follow and run at once, and both motor and perceptual capacities appear to be adequate very soon after birth.

EXPERIMENTS ON THE EFFECTIVE STIMULI FOR DISCRIMINATING DEPTH ON THE VISUAL CLIFF

It was pointed out, in describing the apparatus, that a jump or sudden transition in texture density (Figure 1) characterizes an edge, and that a difference in the amount of this transition (Figure 2) characterizes the difference between the shallow and the deep edge of the platform, i.e., the amount of drop-off. When the same pattern is used directly under the glass on one side and at the floor level on the other side, the size of the elements of the texture, as projected to the head of the animal, will be quite different. Is it this texture density difference that is effective in producing the differential behavior? Would the texture density difference suffice alone? What other stimuli are available and could they also serve as cues?

Although Figures 1 and 2 do not show it, two other types of stimulus information about the drop-off are possible. The first is a jump in the motility of the texture at the edge, caused by head movement parallax,

and the second is a jump in the disparity of the texture at the edge, caused by binocular parallax. (A diagram of the first is to be found in Gibson & Walk, 1960.) The question is whether our animals could register or respond to this supplementary information.

The anatomical evidence suggests that all animals with eyes are sensitive to motion perspective, but that only some can register disparity perspective—presumably those with the greatest degree of overlap of the binocular fields of view. It is known that man can see depth in a stereoscope, but what other animals can do so is not established. We did not attempt to test for the effectiveness of binocular disparity as a cue, but did for motion parallax, since it is universally potentially present as a stimulus. We decided to try to isolate the difference in texture density from any accompanying difference in motion parallax, and then to isolate the difference in motion parallax from any accompanying difference in texture density.

The use of motion parallax is not only possible, but highly probable for all the subjects. Head movements of the animal as it moves its head or walks along the edge will produce a much greater differential velocity of the texture elements, relative to the edge of the board, for the deep side than for the shallow. Or, if the animal compares one side with the other, the apparent velocity of the optical textures on the two sides provides a differential stimulus for the two. The density difference, then, and the parallactic motion of the projected stimuli caused by the animal's own movement appear to be two universal types of potential stimulus information for depth in the cliff situation. Are they effective, as well as potential?

The following experiments, then, tested the role of these two stimuli by attempting to separate them experimentally. Rats and baby chicks were used principally for these experiments, since the smaller apparatus for them made total control of stimuli easier. The large room required for testing the human infants, for instance, made isolation of the sources of differential stimulation impractical. The rats and chicks were plentiful and their entire field of view could be manipulated experimentally.

Comparison of Texture Densities

Is a coarse texture density preferred to a fine texture density, when other cues to depth are eliminated? The first experiment on this question was performed with adult hooded rats. The second apparatus (Model II) was employed with the coarsely checked texture ($\frac{1}{4}$ " squares) placed on one side of the apparatus, and an identical but smaller pattern ($\frac{1}{8}$ " squares) on the other side. The textured patterns were directly under the glass on both sides. There was, therefore, no actual difference in depth between the two sides. But the density difference was the same as that projected to the animal's eye when the coarse pattern was on the floor 10" below on one side and under the glass on the other. If a density difference alone is an effective stimulus for perceiving a depth difference, the animals might be expected to show a preference for the side having a coarse texture. The two sides exhibiting the coarse and the fine texture were alternated, in this experiment, so that no bias for one direction or the other could be confounded with the density difference.

Table 15 shows that these hooded adult rats did exhibit a significant preference for the side floored with the coarser texture. The preference is not quite as pronounced as that usually found with these animals when the density difference is caused by one

surface placed farther below than the other (93% as compared with 100%).

A group of adult albino rats was also run on this experiment, but the density ratio was increased. The squares of the coarse texture were $1\frac{1}{8}$ " on a side, while those of the fine texture were $\frac{1}{8}$ ". Under these conditions, the albino rats showed some preference for the coarse texture (69% descended on this side, compared with 19% on the other).

A group of young hooded rats (29-31 days old) was run with the same density difference as the adult hooded group. They showed a similar preference (87.5% to the coarse texture and only 8.3% to the fine texture). All the rats, then, showed a discrimination of texture density and a preference for the coarser one.

Any textured surface, actually, is probably preferred to a homogeneous one which provides no cues for a surface. A group of hooded rats ($N = 10$) was run with $\frac{1}{4}$ " checks on one side of the board and a homogeneous grey surface on the other, both directly below the glass. All of the animals that left the board (90%) descended to the textured side.

A control experiment was performed to find out whether rats would prefer coarse textures to fine textures in a different situation. A Y maze was covered with textured surfaces as follows: the stem of the Y was covered with homogeneous grey and one arm was covered with the $\frac{1}{4}$ " checks, the other with $\frac{1}{8}$ " checks. Twenty-four animals were placed on the grey stem and the exploratory behavior was observed for 3 minutes. The animals explored the maze freely but neither in the initial choice of arm (10 chose the coarse pattern, 12 the small one, 2 stayed on the grey) nor in total amount of time spent on either arm did they exhibit any preference for the coarse texture. It would seem, then, that the preference for the coarse texture is related to *descent* from a board where the animal has a choice of a coarse or a more finely textured surface. That the behavior is based on choice between two surfaces was suggested by another experiment where the surface below the animal was varied in texture but the

TABLE 15

ANIMALS DESCENDING TO THE COARSE OR TO THE FINE TEXTURED SURFACE, DIRECTLY UNDER GLASS ON BOTH SIDES

Animal	<i>N</i>	$\frac{\%}{\text{to}}$ coarse textured surface	$\frac{\%}{\text{to}}$ fine textured surface	$\frac{\%}{\text{no de-}}\text{sc-}$ cent
Adult hooded rats	37	84	16	0
Adult albino rats	16	69	19	12
Infant hooded rats	24	87.5	8.3	4.2
Baby chicks (1-2 days)	46	33	46	21

cliff was one-sided as in the threshold experiment (see earlier discussions). Latency of descent was measured to four surfaces: red checked squares of $1\frac{1}{2}$ ", $\frac{1}{2}$ ", $\frac{1}{4}$ ", and $\frac{1}{8}$ ", all 4" below the animal and directly under the glass. Latencies tended to be longer only for the $\frac{1}{8}$ " squares; the others were the same.

It was a matter of considerable interest whether another species would show this preference for descending to a coarsely textured floor as opposed to a finely textured one. Accordingly, a group of baby chicks, 1-2 days old, was run with the same apparatus and conditions as the hooded rats (except for lowering the center board height to 2"). The chicks were observed for a 10-minute interval, rather than a 3-minute one, since they were much slower to descend. But the chicks, as Table 15 shows, did not behave like the rats. There not only was no preference for descending to the coarse textured floor, there was even a greater tendency to descend to the finely textured surface. The difference (33% vs. 46%) is not significant, but the chicks differed significantly from the rats.

The large cliff (Model III) was employed to test two young goats (12 days old) in a similar setup. The pattern on one side was 3" squares, in a checkered pattern, that on the other $\frac{1}{4}$ " squares. The center board was 3" high. Both kids left the center board at once, one walking first to one side, one walking first to the other. Both wandered about impartially from one side to the other. It is conceivable that a preference might have appeared if they had had to descend from a greater height, but under these conditions the behavior was equivalent for the two sides.

Why should the rats descend nearly always to the coarse textured surface, composed of large elements, whereas the chicks and goats show no such preference? This difference in choice of substrata might be an innate species difference. We cannot draw such a conclusion from these data, however, since there is another difference, that of age, between the chicks, at least, and all the rats. Most of the chicks were less than 1 day old, none more than 2. The

goats, at 12 days, were somewhat older. But even the young rats were a month old and had, therefore, had more visual experience. This experience might somehow provide an opportunity to acquire the preference for descending to a coarsely textured substratum. The possibility was checked in the experiments following in the section on dark-reared animals.

Motion Parallax as a Cue

In order to isolate the role of motion parallax from density, the density ratio had to be *one*; that is, there had to be no difference in optical texture density between the two sides, although one remained farther from the animal's eye than the other. Two patterned surfaces were obtained which were identical in coloring and pattern (alternate squares of white and red) except that the squares in one were three times the size of the other. The material with larger squares was placed on the floor below the apparatus. The material with the smaller squares was placed directly under the glass. The height of the apparatus was adjusted so that the floor on the deep side was exactly three times as far from the animal's eye as was the surface of the shallow side.¹⁰ Thus, texture density (or angular size of the elements) was equated for the two sides. But since one surface was farther away, any movement of the animal's head would produce differential motion by virtue of parallax. That is, the elements of the closer surface would appear to move with a greater velocity than those of the other. This difference was very easy for the experimenters to observe. That the animals did move their heads and thus produce this differential

¹⁰ Assuming that the animal's eye is 1" above the platform whose surface is 4" above the glass, the distance to the shallow surface is 5", to the deep surface 15". If the animal's eye is not precisely 1" above the center board there is a slight density difference but it is much less than in the standard situation and probably not discriminable (if the animal's eye is 4" above the glass, the approximate ratio is .86 to 1.00, at 5" 1.00 to 1.00, and at 6" 1.11 to 1.00; when the animal's eye is 5" above the glass in the standard situation the ratio is .33 to 1.00 or a 3 to 1 ratio).

stimulation was also obvious. The rats typically moved their heads vertically up and down in a bobbing motion looking first on one side and then on the other. They also frequently walked the length of the board looking from side to side. When the animal lowered his head and raised it again, the motion would produce an "expansion pattern" of motion perspective as described by Gibson, Olum, and Rosenblatt (1955) and would yield good potential information for relative depth of the two surfaces.

This situation, for the rats, seems effectively to rule out any other differential stimulation for depth except accommodation (if it is effective at all). Binocular parallax is improbable for this animal. Brightness was of course equated for the two sides.

Adult hooded rats were run first in the experiment. As Table 16 shows, a preference for the shallow side (83% descended there) existed despite the elimination of the texture difference between the two sides. Even when there was no "jump" in texture from one side to the other, the animals quite consistently chose the shallow side. The stimulus basis for this choice almost certainly was the differential motion parallax.

A group of young hooded rats (30 days old) run in the same situation exhibited an even more consistent preference. All the descents were to the shallow side, and none to the deep. It appears, therefore, that motion parallax produced by the animal's own

movements is an effective differential stimulus for depth in hooded rats.

Finally, a group of 1-day-old chicks was run in the same situation. The chicks do not often make vertical head movements like the rat, but typically dart the head from side to side. In this experiment, a majority of the chicks, like the rats, descended to the shallow side (89% to the shallow, 4% to the deep). Thus the chicks at 1 day of age probably discriminate depth primarily on the basis of motion parallax, since a difference in texture density alone was shown in the previous experiment to be ineffective for them. Perhaps the two stimulus variables, when present together, interact in some way; but it is notable that with parallax present, but isolated from density difference, only 1 of 27 chicks descended to the deep side.

It was decided, in an attempt to check for binocular cues, to try a few monocular chicks on the cliff. Five 1-day-old chicks had one eye removed surgically. Several hours later, they were run on the standard cliff, with $\frac{1}{4}$ " checks on the floor 10" below the glass on one side and directly under the glass on the other. Of these chicks, four descended to the shallow side and one to the deep.¹¹ This distribution may indicate a preference for the shallow side, but this was dubious, since the chicks appeared to fall off, rather than jump. The notable fact about their behavior was a lack of balance. The chicks all leaned toward the side away from the remaining eye, as if they could no longer keep themselves in the upright position. It seemed as if the chick depends on balanced light to the two eyes to keep itself in equilibrium. By the next day posture had

TABLE 16

BEHAVIOR OF ANIMALS WHEN TEXTURE DENSITY (ANGULAR SIZE OF ELEMENTS) IS EQUATED FOR THE TWO SIDES

S	N	% descent to shallow	% descent to deep	% no descent
Adult hooded rats	18	83	17	0
Infant hooded rats	25	72	0	28
1-day-old chicks	27	89	4	7
Young goats	17	100	0	0
Young sheep	12	100	0	0

¹¹ Hess (1956) fitted prisms (base out) to the eyes of chickens and concluded, because they pecked short when viewing binocularly, that "binocular depth cues" were employed. But the phrase is vague. The experiment does not demonstrate that binocular image disparity can be utilized by the chicken, but only that it utilizes simultaneous information from both eyes in pecking. It should be remembered that birds do not have single, concentrated, central foveas, like primates. Whether birds can register depth at an edge by means of binocular parallax as well as by motion parallax is unknown.

improved, but the chicks moved around very little and only two descended from the board. This experiment is inconclusive. It seems likely that binocular vision in the chick has other functions more important than the providing of supplementary information for the discrimination of depth.

When we were able to obtain sheets of material with a large checkered pattern (3" checks), it was possible to equate density of texture with the large cliff apparatus. Directly under the glass on the shallow side was placed material patterned with $\frac{1}{4}$ " checks. On the floor below the deep side and covering a wide area was placed the pattern of similar 3" checks. To obtain a 4 to 1 ratio of height, the glass was set 3' from the floor, assuming that the eyes of the animals to be tested would be approximately 1' above the glass. These animals were kids and lambs, ranging in age from 1-35 days old.

The 17 kids behaved uniformly in a completely predictable way. They were placed on the center board twice, once from either side, and were observed until they left the board and for one minute longer. Every animal, even the 1-day-old infants, walked invariably to the shallow side and avoided the deep side. They peered over the deep side, but turned away from it and walked forward onto the shallow with a normal stride and posture. When they were placed on the glass over the deep side, all but one animal backed up to the wall and stood hunched there, legs rigid, back humped. The other animal lay prone on the glass of the deep side and did not move.

The 12 lambs also all walked onto the shallow side (2 backed onto it). But their behavior was not as consistent as that of the goats. One of them, when coaxed, walked a few steps out on the deep side. Upon looking down, it backed off. One backed, probably without seeing where it was going, onto the deep side. When these animals were placed on the glass over the deep side, they backed to the wall, sometimes kneeling. Two of the lambs went over the side of the apparatus, one falling but the other apparently jumping.

None of these animals gave evidence of responding to the glass as such. It was typical for an animal to bump its nose on the glass of the deep side when placed there by the experimenter.

It seems clear from these experiments that young goats, even at 1 day of age, avoid a drop-off when the motion cue is present and in the absence of a cue of differential size or texture density. Lambs tend to do likewise, but not as consistently.

In conclusion, we feel that motion parallax in rats, chicks, goats, and lambs is of critical importance as a stimulus for discrimination of depth. It appears, as well, to be operating in extremely young and inexperienced animals.

Competing Cues

The question was often asked us what would happen if the cue provided by texture density difference were put in opposition to that of differential motion parallax. We accordingly set up a situation in which the surface on the floor had a pattern containing elements so large (1 $\frac{1}{2}$ " squares) that even at the greater depth the density was less than that on the shallow side ($\frac{1}{8}$ " squares, identical shape and color). The density cue would then favor the physically deep side, but differential motion parallax would still exist and would favor the shallow side. Two groups of animals were run in this situation, hooded and albino rats.

In both groups, more animals descended to the shallow side than to the deep, though the difference was not as great as in some of the other experiments (see Table 17). A quarter of the hooded rats did not descend, a rather large number for adult animals. The evidence on the whole supports the conclusion that motion parallax is the more effective cue when the two are put in opposition.

Conclusion

This section reported (a) attempts to isolate the influence of motion parallax by equating the projected texture density on the two sides of the apparatus, and (b) iso-

lation of differential texture density as a cue by putting a coarse texture directly under the glass on one side of the platform and a similar fine texture at the same depth on the other side. All of the species tested, where the size of the optical texture elements was the same while height was varied, so that motion parallax was present without a texture difference, were able to discriminate between the two sides. The monkey (see p. 21), the goat, the sheep, and the chick seem to have as good depth discrimination in this situation as they do with the regular experimental setup where texture density is also a potential cue. The rat, on the other hand, seems to have a slight drop in accuracy under these conditions—the drop is not large or statistically reliable, but it is possible that this animal may require more cues for effective discrimination than do the more strongly visual animals. It cannot be concluded that motion parallax was the *only* effective cue since accommodation may conceivably operate in all species and binocular disparity is debatable.

The experiments where optical texture density was varied by varying physical texture density while height was equal (the density preference series) yielded curious results. The rats definitely preferred the coarser of two patterns (evidence based on three experiments) yet neither the chick nor the goat exhibited a preference for either texture. Experiments on animals reared in the dark may throw more light on this problem and will be reported in the next section.

TABLE 17
COMPETING CUES

<i>S</i>	<i>N</i>	% descent to shallow	% descent to deep	% no descent
Adult hooded rats	16	50	25	25
Adult albino rats	16	62	19	19

Note.— $1\frac{1}{2}$ " (small) pattern on shallow surface, $1\frac{1}{2}$ " on deep surface.

EFFECTS OF DARK-REARING ON DEPTH DISCRIMINATION OF RATS AND CATS

Rearing an animal in the dark prohibits prior visual experience, so that the animal's first "glimpse of the world" is under experimental control. Can animals reared in the dark discriminate depth as well as normally reared animals? This section will report three experiments with dark-reared hooded rats and one with dark-reared kittens.

While some animals, like the chick or the goat, can be tested within 24 hours of birth so that dark-rearing to control prior visual experience is irrelevant, both the cat and the rat do not have adequate enough locomotor ability to be tested on the visual cliff until they are about 4 weeks old. But dark-rearing creates many problems of its own. These problems actually may hinder the experimenter's search for visual naivete, since the differences between dark- and light-reared animals may be due to factors other than the visual experiential ones. The problems of dark-rearing can be divided into physiological, methodological, experiential, and emotional ones. The fact that dark-rearing may have physiological side effects is well known: there was a pronounced pallor of the optic disk in Riesen's dark-reared chimpanzees and neurological examination showed degeneration of retinal ganglion cells (Chow, Riesen, & Newell, 1957). Other physiological effects of dark-rearing may not result in direct damage to the visual system but may interfere instead with other bodily processes and this could affect the normal behavior of the animal when it is tested. For example, the light cycle controls gonadal development in birds; thus in some species dark-rearing might induce aberrations in behavior unrelated to vision that could lead to different behavior in the testing situation (cf. Brown, 1959; Hendricks, 1956). A second source of difficulty is methodological. Few studies of dark-rearing raise animals under conditions such that differential light stimulation is the only experimental variable. The light-reared, for example, can usually see laboratory personnel and thus become adapted to the sight of humans. Testing conditions may also not be equiva-

lent for the dark-reared and the light-reared. The practice of keeping the dark-reared in the dark except for testing while the light-reared are kept in the light, causes differential dark adaptation which, rather than prior experience, might be a factor. A methodological problem arises in connection with light stimulation itself. The only variable purposely controlled has been patterned light exposure as compared to non-patterned, translucent exposure (Mishkin, Gunkel, & Rosvoid, 1959; Riesen & Aarons, 1959; Siegel, 1953). Yet the studies of Hebb's students (Forgays & Forgays, 1952; Hymovitch, 1952) have shown that depth in the field of view may be an important variable: animals reared with adequate patterned light experience but with a field of view that included only near objects did not perform as well in maze learning as those with an unrestricted field of view. The third problem in dark-rearing, that of the control of specific early behavior, has not been the topic of research, but its possibility is well known. The dark-reared animals may learn other habits, to rely on nonvisual cues for example, and hence perform inadequately in visual problems whether their present visual system is adequate or not. Dark-reared animals may also be more "emotional" (Gibson et al., 1959). This can be due to disturbance at the unexpected light stimulation or it might conceivably be a physiological side effect of dark-rearing.

All of these factors show that dark-rearing for control of prior visual experience may lead to complications. For these reasons, animals in the following experiments were maintained in as equivalent conditions as possible, in the hope that differential light stimulation up to the moment of testing was the main variable. Weights were also taken of the rats to make sure the general pattern of development was comparable in light- and dark-reared.

Rats

In the first study rats were reared in light or dark, but otherwise identical, environments for the purpose of comparing depth discrimination 20 minutes after the

dark-reared animals were first exposed to the light. The second study investigated the stimulus determinants of depth discrimination after differential rearing. Animals were reared in the same cage environments and one group of light-reared had patterned light experience but a restricted depth of field. In addition, all animals were tested after being removed from a dark room so that light adaptation was equivalent. The third study continued the investigation of stimulus determinants with 30-day-old animals. While the dark-reared were kept in the same environment as that of the second study, the light-reared were raised in the main laboratory colony.

The first experiment using dark- and light-reared animals has been reported before (Walk, Gibson, & Tighe, 1957). Animals were kept in identical wire mesh cages surrounded by cardboard walls, some within a lightproof room and others in a similar, lighted room. At the age of 90 days, animals were removed from the dark and tested on the original apparatus. The results are shown in Table 18. In depth discrimination, there is no difference between dark- and light-reared. While the latencies look higher for the dark-reared, they are not significantly higher. In the discrimination learning portion of this experiment, the dark-reared animals were much harder to pretrain but this "emotionality" did not seem to affect behavior on the visual cliff.

The second experiment with dark-reared animals also used adult hooded rats. In this experiment, there was more precise control of the environment to increase the certainty that the differential visual experience was the critical experimental variable. Eight wooden boxes of 4" pine were constructed of identical size with outside dimensions 47" long \times 12" high and 11 $\frac{1}{2}$ " deep. All boxes were covered in the front by a door framed with glass hinged at the top, the glass measuring 9" \times 43". Additional ventilation was supplied by ventholes in the rear of the boxes which were mounted 2 $\frac{1}{2}$ " away from the wall. For the light-reared, five boxes mounted on top of each other were used.

TABLE 18
DEPTH DISCRIMINATION OF ADULT HOODED RATS IN THE FIRST DARK-REARING EXPERIMENT

Group	N	Shallow side		Deep side		% no descent
		% of descents	Median latency (seconds)	% of descents	Median latency (seconds)	
Light-reared	29	80	1	10	5	10
Dark-reared	19	74	5	16	20	10

Note.—In this experiment the animals were placed on the center board in a box to avoid handling bias.

The remaining three were for the dark-reared. The rearing procedure assured that ventilation, auditory, and olfactory experience would be similar for both groups.

The light-reared were housed in a room of identical size as the dark-reared. Lighting was supplied by 60-watt bulbs, two being located on each side of the boxes, one pair near the top of the tier, one pair at the bottom of the tier, so that bulbs were not visible to the animals. The three bottom tiers were also faced with white cardboard 4" in front of the glass. Thus, approximately half of the light-reared had a visual environment that extended through the glass and around the room, while the others' visual environment extended only 4" (these will be referred to as the full vision group and the restricted vision group, respectively). Lighting was controlled by a poultry timer so that lights were on from 10 P.M. to 10 A.M., off from 10 A.M. to 10 P.M. The lighting cycle insured that when the animals were to be tested in the afternoon, they would be tested on emergence from the dark so that light adaptation would be equivalent for all groups.

For the dark-reared rats, black cardboard was taped over the front of the glass as an additional precaution against the admission of light.

Litters were split and the pups distributed among the three groups shortly after birth. All animals were reared in wire mesh cages 20" long \times 9 $\frac{1}{2}$ " deep \times 6 $\frac{1}{2}$ " high, placed inside the wooden boxes, until they were 30 days old. At that time, the animals were weaned, the sexes separated,

and the subjects placed two to a cage in cages 6" wide \times 6" high \times 8" deep, five cages to a box.

The animals were tested at 90 days of age, about 20 minutes after removal from the dark. The testing was spread over several days, testing by group randomized, and subjects returned to the dark after testing. All animals were in good health when tested. No weight differences among groups were observed, the median weights, by sex, being distributed as follows: light-reared full vision group, males 288 grams, females 193 grams; light-reared restricted vision group, males 310 grams, females 201 grams; dark-reared males 295 grams, females 189 grams.

Approximately half of the animals in each group were tested on the setup with equal texture density but height variable (see section on Experiments on the Effective Stimuli for Discriminating Depth on the Visual Cliff), the other half on the setups with texture density variable but actual height equal. Each animal was tested only once. As Table 19 shows, all groups behaved similarly in the equal density situation, about 70% descending from the board to the shallow side which contained $\frac{1}{4}$ " squares under the glass and 30% to the deep side where the $\frac{1}{4}$ " squares were 10" below the glass. We infer, therefore, that motion parallax can operate to produce differential behavior in all three groups, including the dark-reared.

In the series with texture density variable but height equal, on the other hand, the three groups did not behave in the

TABLE 19

COMPARISON OF ADULT HOODED LIGHT- AND DARK-REALED RATS ON DEPTH DISCRIMINATION WITH DENSITY EQUATED AND ON PREFERENCE FOR PATTERN DENSITY

Group	N	% descents	Median latency (seconds)	% descents	Median latency (seconds)	% no descent
Shallow side						
Deep side						
I. Equal density; height variable						
Light-reared, full vision	10	70	15	30	45	—
Light-reared, restricted vision	11	73	21	27	24	—
Dark-reared	12	67	12	25	27	8
Large pattern						
Small pattern						
II. Texture variable; height equal						
Light-reared, full vision	11	82	10	18	18	—
Light-reared, restricted vision	10	50	5	50	20	—
Dark-reared	12	33	20	67	13	—

same way. The light-reared full vision group showed a preference for the large pattern (82% chose this side), confirming the results reported in the preceding section for a similar experiment with adult hooded rats and again with 30-day-old ones, all reared under normal conditions in a large colony room. But the animals raised under conditions of restricted vision did not show a preference for either texture. The dark-reared group even reversed the preference, though the number of cases is too small for a statistically reliable difference. The results suggest that rearing conditions may in fact alter the role played by texture density as a cue.

The third dark-rearing experiment used young hooded rats 30 days old. The animals lived from shortly after birth in the boxes in the dark room described in the second experiment until ready for testing. Litters were not split. Instead, these animals were compared to young animals (25-33 days

old) reared in the normal colony environment. Light-reared animals were kept in small cages which permitted full vision through the sides and top of the cages.

The young animals were tested approximately 20 minutes after leaving the dark. Separate groups were tested on the standard height discrimination, on the depth discrimination with texture density equated but height variable, and on the preference for two patterns of varying density ($\frac{1}{2}$ " and $\frac{1}{4}$ " squares) directly under the glass. As Table 20 shows, the young dark-reared animals behaved similarly to the light-reared on both the standard depth discrimination and the equal density one, confirming the experiments with adult hooded dark-reared and light-reared animals. The density preference results were also similar to the results with adult animals in the second dark-rearing experiment, that is, a slight preference for the fine pattern in the dark-reared as against a marked preference for the

coarser pattern in the light-reared. For this experiment, the light-dark-reared difference on size preference is statistically significant ($p < .01$). The importance of rearing conditions for the role played by texture density was thus confirmed.

It seems clear from these experiments with the dark-reared animals that some depth discrimination in the rat is unlearned, that motion parallax is effective as a cue without learning, but that a difference in texture density alone does not operate in the same way in light-reared and dark-reared rats. How experience might affect the role of this variable will be discussed later.

Dark-Reared Cats

In view of the near equivalence of behavior of normally-reared and dark-reared rats, it seemed interesting to compare a more strongly visual animal such as the cat under these two conditions. Two pregnant

cats were brought to the laboratory shortly before parturition and housed there. Each cat was kept in a wire mesh cage 26" \times 26" \times 26" in a large animal room. About 5 days after the kittens were born, the cage with mother and litter was removed to a large darkroom. The room was well ventilated but no light whatsoever entered. Care of the cats demanded a small amount of light when the experimenters entered to feed the animals and clean cages. A photographer's red flashlight was used for this purpose. No other light entered with the experimenter, since the room was approached through double doors with a small unlighted corridor between them. One door was closed before the other was opened. Care requiring the use of the flashlight took approximately 10 minutes a day.

One of the mothers was restless in the darkroom. She howled and attempted to escape from the cage. She was, therefore, given a tranquilizer (10 milligrams of

TABLE 20
LIGHT-READED AND DARK-READED HOODED RATS 30 DAYS OLD
COMPARED IN PERFORMANCE ON THE VISUAL CLIFF

Condition	N	Shallow side		Deep side		% no descent
		% descents	Median latency (seconds)	% descents	Median latency (seconds)	
Standard: both height and density varied						
Light-reared	22	77	29	5	8	18
Dark-reared	14	79	34	14	17	7
Equal density: height varied						
Light-reared	25	72	23	0	19	28
Dark-reared	20	65	35	20	19	15
Texture density varied: height equal						
Light-reared	24	88	14	8	21	4
Dark-reared	22	36	18	50	10	14

chlorpromazine) twice a day. She was removed from the darkroom for this purpose and returned to her litter again immediately after medication was administered. The drug had the desired effect; she settled down and cared for her litter as adequately as the other cat. The drug was discontinued a day before the kittens were brought out. It did not appear to affect them, however, since they seemed throughout to be as lively as the other kittens.

The kittens were removed from the darkroom when they were 26 days old and kept thereafter in the lighted animal room where they were born. When they were first brought out they were kept for 20 minutes in a box arranged to provide only homogeneous light, and were tested on the cliff immediately upon removal from the box.

The light-reared kittens with whom these were compared have already been described. They were reared in the laboratory in a cage identical with those housing the dark-reared animals and in the same animal room where those animals were born. They were tested when they were 27 days old (see Comparative Experiments).

Each dark-reared kitten was tested on the large cliff with a $2\frac{1}{2}$ " high center board, exactly as the control litter (27 days old) had been tested. Six trials were given, one after another, each lasting 2 minutes. Upon completion of these, the kitten was placed in the center of the glass on each side and its behavior there observed.

After the first day, the kittens were each observed for two trials daily for 15 days in order to determine the progress of further maturation. They were also observed for the visual placing response, following a moving object with the eyes, and general visual motor coordination.

All the dark-reared kittens ($N = 9$), when first brought out, appeared to have no responses to visual stimulation except the pupillary reflex. There was no visual placing response (cf. Riesen & Aarons, 1959), no following response, no blink, and the kittens bumped into walls which were squarely in front of them. Their movements were awkward; they crawled, rather than walked, keeping their stomachs in

contact with the ground. When they were placed on the center board of the cliff, they either remained still (no descent), or fell off after moving a short way. They were as likely to fall forward as backward. Table 21 shows the place of descent (or no descent) for these animals. It can be seen that the animals descended about equally often to either side, and one-third of the time did not descend. Furthermore, no single animal showed a preference for either side. In great contrast to this behavior is the record of the light-reared kittens of the same age. None of them descended at all to the deep side, and 86% of the time they descended to the shallow side. Every kitten showed a preference for the shallow side.

The dark-reared kittens, after the first day's tests on the cliff, were placed on the center of the glass of each side as the light-reared ones had been (described in Comparative Experiments). The light-

TABLE 21
BEHAVIOR OF DARK- AND LIGHT-REARED KITTENS
27 DAYS OLD ON VISUAL CLIFF

	Times to shallow	Times to deep	No descent
Dark-reared			
Ia	3	2	1
Ib	1	3	2
Ic	2	2	2
Id	3	3	0
Ie	1	1	4
IIa	1	2	3
IIb	0	2	4
IIc	3	1	2
IId	3	3	0
%	31.5	35.2	33.3
Light-reared			
1	6	0	0
2	5	0	1
3	6	0	0
4	6	0	0
5	3	0	3
6	5	0	1
%	86	0	14

Note.—Each kitten was tested six times for 2-minute intervals.

reared kittens behaved very differently on the two sides; they characteristically hugged the wall or backed in a circle on the deep side, but simply walked forward on the shallow side. The dark-reared kittens did not make such a distinction. The behavior varied for different animals. One animal circled on both sides; one walked, or rather crawled, toward the wall on both sides (perhaps getting echoes from his constant mewing); some simply sat still; several walked into a wall and bumped their noses.

The kittens, then, did not mature visually in the dark. Rats and cats are thus clearly different in this respect. But do the dark-reared kittens catch up to their controls in the light? And how long a period is required before normal behavior is achieved? Figure 12 shows the percentage of descents to the shallow side as compared to the deep side from the day the kittens were brought out of the darkroom through the seventh day in the light. (The no descent category has been disregarded here, since this changed very little from day to day. The two curves in Figure 12 are thus reciprocal.) On the first day, descents were divided about equally between the two sides. Thereafter, the preference for

the shallow side increased rapidly and became complete (100%) by the seventh day. No kitten tested after the seventh day chose the deep side. Therefore, the normal preference for descending to the shallow side developed as the kittens lived in the light. We infer that this is based primarily on maturation of visual discrimination of the depth differences. There was no reinforcement for choosing the shallow side; if anything, the kittens should have learned that the deep side was safe, since they descended there in the beginning without harm.

The other visual-motor behavior of the kittens did not seem fully mature before 10 days or more, in all cases. By the fourth day, the cats followed a moving object, mostly by jerking the head sideways. By the fifteenth day, good pursuit movements of the eyes could be observed. The experimenters never observed convergence movements, but it is dubious whether these are generally present in normal cats.

The visual placing response appeared in gross form in some cats after a few days, but it was not a well-coordinated placing of one paw (as it is in the normal 27-day-old kitten) until about 10 days out. Motor coordination developed gradually, too. By the fourth day, few animals slipped off the board (some still did, however), the curious crawling locomotion had in most cases given way to upright walking, and some of the animals had lost the staring-straight-ahead look of the first day as eye movements began to appear. None of the times given here can be considered as absolute, since different housing conditions (a whole room instead of a cage, for instance) might have speeded up maturation.

Finally, the behavior of the cats when placed on the glass of the deep side changed. Here are some typical protocols for four animals on the eleventh day out:

1. Circles and backs to wall.
2. Circles backward.
3. Crawls on stomach to wall, then backs along edge.
4. Crawls to wall and walks forward along edge hugging wall and stepping on glass over supports only.

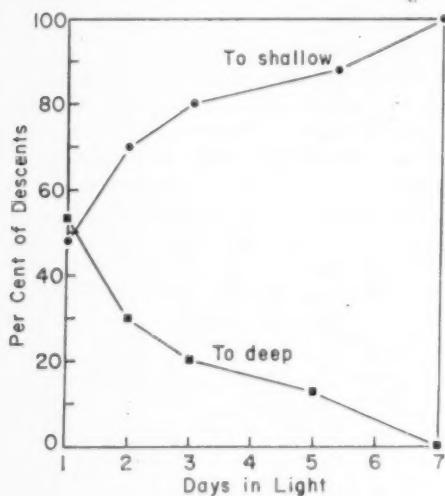


Fig. 12. Percent of descents of dark-reared cats to a deep or to a shallow surface as a function of days in the light.

This behavior was quite different from that when the animals were placed on, or stepped down to the shallow side, where they walked about freely.

We conclude from comparing the behavior of dark- and light-reared kittens at 27 days that response to visual stimulation had not matured normally in dark-reared animals. However, as the dark-reared kittens lived in normal conditions of daylight thereafter, there was gradual maturation of the response to visual stimulation, apparently complete by about 10 days. The reaction to visual support, or lack of it, was observed especially and was found absent on emergence from the dark but entirely present after 10 days in the light. This development occurred without any external reinforcement in the experimental situation.

Conclusion

At the beginning of this section certain problems of dark-rearing were discussed. Despite the difficulties of experimental inference sometimes involved in dark-rearing experiments, our studies yielded very clear-cut results. The dark-rearing experiments, on the hooded rat and the cat showed a striking species difference between these animals since dark-reared rats were not deficient in visual depth discrimination when first brought into the light, whereas the cats were. However, this ability matured in the cats after a few days in the light. That the ensuing development was primarily continued maturation was inferred, since no reinforcement in the experimental situation was provided.

The role of differential texture density and differential motion parallax were studied with dark-reared rats, with the result that motion parallax appeared to be as effective as a cue in dark-reared as in light-reared animals, while texture density was not.

DISCUSSION OF RESEARCH AS A WHOLE

This research has been concerned with a comparative and analytic investigation of depth perception as evidenced by the avoid-

ance of a cliff. This type of depth discrimination is highly adaptive and is, in fact, manifested by many species, as we have shown. In discussing the results, several related questions arise. First, is the discrimination of depth learned? Second, is the fear of cliff edges that presumably goes with potential loss of support learned? Finally, are species comparisons possible?

Depth Discrimination and Learning

It was not the purpose of this research to solve the "nature-nurture" problem which has, rightly or wrongly, caused psychologists to do battle with one another for centuries (see Hochberg, *in press*). Our purpose, as stated, was a comparative investigation of depth perception with a technique which could be used identically for many species, at an early age and without special training. But the question was asked us over and over again, is it innate or is it learned?

Since the technique can be applied without special training, often when the animal has had no previous visual experience at all, there are, in the results, data which are relevant to the nature-nurture issue. It seems well to state these explicitly and to consider what light, if any, has been thrown on the problem.

Two kinds of experiments have a direct bearing. First, the experiments on very young animals (1-day-old or less), and second, experiments with dark-reared animals.

Experiments with animals less than a day old were possible with chicks, lambs, and kids, since these animals are capable of locomotion shortly after birth. When tested at this time with the standard cliff situation, all the subjects observed, of these three species, showed good discrimination of depth; as good, in fact, as the older animals of the same species. Perhaps someone would point out that there have been a few hours of exposure to visual stimulation before the test took place. While this was true, any learning which occurred in this interval must have been

very limited indeed. There could have been little or no opportunity to learn through reinforcement by falling or through tactual and kinesthetic confirmation of different surface depths by actual exploration or climbing up and down.

The second case is even clearer. Rats reared in the dark discriminated between a long and short drop-off 20 minutes after removal from the darkroom. Also, Nealey and Edwards (1960) repeated this experiment and had animals adapt in homogeneous light instead of patterned light. In all cases, the discrimination was still effective. The conclusion, confirming Lashley and Russell (1934), seems inescapable, that in hooded rats the ability to discriminate depth is innate. We cannot assume that this conclusion applies to other species. But if it is true of some, then theories that attempt to explain space perception must allow for a built-in mechanism in at least one species.

The dark-reared cats did, of course, present a different picture. They did not discriminate 20 minutes after removal from the dark, but they did after 3 or 4 days of living in the light, in a cage. Did they learn during this time, and if so, what? The cats were tested on the cliff on succeeding days (their only opportunity for locomotion outside the cage). Reference to Figure 12 shows that the preference for the shallow side increased by the seventh day in the light to 100%. Why? The animals had equal experience descending on the two sides in the beginning; according to a reinforcement learning theory, they should have learned that descent to either side was perfectly safe—the glass surfaces were identical tactually and kinesthetically. How is the visual difference learned, if not by confirmation? And if one supposes it is learned without differential reinforcement, how is the eventual behavioral preference acquired? Despite the different early experience, their preference for the shallow side gradually grew to that of the normal animal. It seems most reasonable, therefore, to adopt the hypothesis that retinal processes were maturing in these animals which required the stimulus of a certain amount of light,

probably patterned light. If this is learning, it does not fit any current definition.

In the monkey as well, there seems to be evidence of maturation after birth. When first presented with the cliff (at 10 days and 12 days) the two monkeys showed uncertain discrimination and actually crossed the glass of the deep side. But the behavior of the animals over the deep side was markedly different from that on the shallow half. Two weeks later, nothing (bottle, blanket, calling by the experimenter who cared for them) would induce them to cross. This evidence is, so far, inconclusive and investigation must be pushed further (perhaps with experience in the situation every day), but it suggests a maturing visual mechanism rather than learning.

Evidence from the human infants does not carry us much further. They had ample opportunity for visual experience by the time they were tested. There was no evidence that the infants had acquired a tendency to avoid a drop-off or to fear heights from having fallen off them. Younger subjects, barely crawling, discriminated depth, if they could be tested at all, as well as the older ones. The evidence from the human infants fits in so well with other late maturing species as to make it plausible to ascribe this depth discrimination at least in part to built-in mechanisms. A learning explanation cannot definitely be disproved, but it would need to be greatly elaborated to permit any testable hypotheses. On the one hand, phylogenetic continuity should not be denied. On the other hand, the complexity and redundancy of stimulation for the discrimination of depth in the human species make any categorical decision premature and ill-considered. Practice has been demonstrated to improve some kinds of distance judgment in the human adult (Gibson & Bergman, 1954). The interplay of innate and learned factors is a problem needing study and research.

Another aspect of the nature-nurture question can be examined with regard to the rat. We know that the hooded rats had a strong innate preference for the shallow side of the apparatus. On what

differential stimulation could this depend? When an attempt was made to separate the cues of density difference and motion perspective, light-reared rats seemed to show a preference when either of these alone was present (differing on the two sides). But the density difference as such elicited no preference in the dark-reared rats. Motion parallax isolated from density did. The inference is that the density gradient had somehow acquired cue value (when the animal is looking down) in a light-reared animal. The fact that the 1-day-old chicks, lambs, and kids did not respond preferentially to a difference in density alone but did when differential motion parallax was present without a density difference supports the inference.

If the cue for the density difference is acquired, it should follow that the dark-reared rats, after exposure to light, should acquire the preference and be similar to normal light-reared animals. In order to test this prediction a group of dark-reared animals was tested twice on density preference, once immediately after removal from the dark and again after a week in the light. Similarly, a group of light-reared rats of the same age (30 days) was tested when the dark-reared were run and again one week later. On emergence from the dark, the 20 dark-reared subjects went as follows: 6 subjects (30%) chose the large ($\frac{1}{4}$ ") pattern, 8 subjects (40%) the small ($\frac{1}{4}$ ") pattern, and 6 subjects (30%) did not descend from the center board in 5 minutes. One week later 13 subjects (65%) chose the large pattern, 2 subjects (10%) the small one, and 5 subjects (25%) did not descend from the center board. Among the 22 light-reared, 17 subjects (77%) chose the large pattern and 5 subjects (23%) the small one on the initial run. One week later the light-reared split as follows: 15 (68%) picked the large pattern and 7 (32%) the small one. Among the dark-reared, then, exposure to light leads to behavior similar to that of the light-reared, and a second testing experience does not change the preference in the light-reared.

It is interesting to hypothesize, from this evidence, that selective response to differential motion parallax (or better, motion perspective) is built into the rat, the chick, and the lamb; but that the step in density, unaccompanied by differences caused by motion, had acquired cue value for the rat on some contingency basis. In the normal environment, presumably, when the animal looks downward, a change in density accompanies motion perspective and can become associated with whatever avoidance or approach behavior is elicited by the motion cue. It has some "ecological validity," to use Brunswik's term, and thus becomes to some extent effective itself.

Whether the density stimulus alone would ever acquire cue status for the goats, sheep, and chickens we do not know. Motion cues are so important for the ungulates that the visual environment without them may be totally disregarded. But here we are on very unsafe ground.

Our studies have seemed to show that discrimination of depth develops differently in different species, in the rat and the cat, for instance. Development continues after birth and requires a certain amount of light in the cat (and probably the monkey). To account for this development by a mere reference to learning appears naive indeed. What kind of learning? What kind of opportunity? The latter question, at least, is open to experimental investigation.

Fear and Loss of Support

The second topic we wished to discuss was the relation of behavior on the cliff to fear and to loss of support. A brink is avoided and it is highly adaptive for an organism to avoid it. Does our research throw any light on the fear of a falling-off place?

While our research technique may be based on the assumption that a high place is dangerous, the simple choice of a "shallow" in preference to a "deep" side does not enable us to conclude that fear is the basis for such a choice. The threshold experiment, where fewer animals descended as height was increased, is the only ex-

periment that directly relates increasing height with an increasing tendency to avoid a drop-off.

However, we investigated the phenomenon of "optical support" (or "visual support") more directly by placing animals on the glass of the deep side, on a transparent surface 40" above the floor. Optical support might be defined as a relatively coarse optical texture of the array surrounding the animal's feet. Optical support, so defined, is usually accompanied by *physical* support; that is, by the ordinary stimulation of the vestibules, muscles, and skin, caused by gravity and the substratum, which controls equilibrium and posture. But our method permits the elimination of optical (visual) support without affecting physical support. This test served two purposes. First, the reaction of the animal to the loss of visual support can be observed and, second, such a test permits a study of the importance of vision to the species investigated.

The strongest reaction to the lack of visual support was observed in the ungulates (lambs and kids). The noses of these animals bumped the surface as they were lowered onto the glass and they executed a reflex-like backing response accompanied by forelimb rigidity. This reflexive postural attitude could only be removed by the addition of visual support to the surface directly under the animal. This reflex in these animals is as strong and stereotyped as were Sherrington's (1906) reflexes.

The cats reacted to the loss of visual support by circling backwards and mewing until a visual surface was reached. Puppies usually backed up, too, after a period of immobility with trembling in some cases. The monkeys lay flat, apparently frightened, above the visual void. Few systematic observations were made of human infants but the ones carried out suggest that the human infant is uneasy without some visual support. Chickens exhibited a peculiar high stepping gait when walking on the glass of the deep side. Rats, on the other hand, and aquatic turtles behaved over the void much as they did over a solid surface.

Observations on the lack of visual support were not quantified, as were those on descent from the board. This is because the observations were carried out only incidentally to the main line of investigation. But, tentatively, we may offer these hypotheses:

1. An animal's response to the lack of visual support is unlearned, a reflex that is characteristic of its species.
2. An animal's response to the lack of visual support is related to its way of life. Visual cues are least important to the rat, intermediate in the kitten, and relatively more important to the ungulate.

However, more systematic research is needed on reactions to the loss of visual support.

Comparison of Depth Discrimination in Different Species

The question of species comparison has been central to the whole plan of this investigation. Our studies have made it clear, if it was not so already, that such comparison is not very enlightening on a quantitative basis alone (such as thresholds). All the species tested on the cliff showed some discrimination between the shallow and the deep side, even the aquatic turtle. This is our main conclusion, and in this respect all species were similar. But this is not to say that there were no differences among the species. Which kinds of potential stimuli are actually *effective*, and under what conditions, undoubtedly varies with the species.

The term "effective" covers a number of problems. What determines whether a stimulus is effective or not? First of all, built-in structures; an animal cannot make use of binocular disparity unless it has two eyes, overlapping fields of view, convergence movements to bring the latter together, and so on. Sometimes maturation to a given stage must be considered, as witness the difference between the chick and the rat or cat at birth. Again, conditions of maturation making for "normal" stimulus effectiveness may vary, as evi-

denced by the apparent necessity for some light in the environment of the cat, as against the rat. In fact, the kind of light in the environment, and the range of surfaces and objects visible may make a difference in later discrimination (e.g., depth of field of view, in the case of hooded rats tested for preference of texture densities). Perhaps even specific reinforcement, or feedback from motor performance can make a difference in some species, though we have found no evidence for it.

Effectiveness of stimuli also varies, clearly, with the species' normal environment and way of life. A rat must be forced to make a choice on the basis of visual cues, but for the goat or chick, even at birth such a choice seems to be natural. It is necessary, therefore, to take a lesson from the ethologists and consider how the kind of discrimination to be compared fits with the ecology and biological requirements of the species—its method of reproduction, defense, food-getting and territorial adjustment. A real comparative psychology will only be written in such a context.

One lesson for theories of perception can perhaps be drawn from this research because it permitted a comparative survey. The old treatises on depth perception attempted to analyze it in terms of points in an abstract geometrical space. But such success as we have achieved seems to us to be founded on the treatment of space in terms of surfaces, depth at an edge, density, and differential motions produced by the animals' own actions. Differences in stimulation described in such terms can also be meaningful in describing ecological differences correlated with species differences. Air, water, and grass covered earth can be described in these ways, and are certainly of critical importance in comparing differences in visual discrimination between birds, aquatic animals, and terrestrial ones.

Finally, we can suggest that the nativism-empiricism controversy be abandoned as such, with the aim of restating the problems of development more specifically. They should be stated in terms of the species under consideration, its environment and means of adjusting to it, and especially in

terms of the information provided by the environment for this adjustment. Whether the animal has the necessary receptor mechanisms for picking up the information input, whether growth in a special kind of environment is required, and whether learning on either a contingency or reinforcement basis is required for making the potential input effective are all questions which can be answered in the laboratory.

SUMMARY AND CONCLUSION

The experiments which have been described made use of an optical testing situation which permitted comparative studies, and which allowed the same essential stimulus variables to be applied to a number of different animals.

All of the animals studied gave some evidence of discriminating depth at an edge. Even the aquatic turtles tended in general to avoid the deep side, though the preference was not as pronounced as in the other species tested, all of which were terrestrial. The discrimination of depth may be less important for some species than for others, and also less acute in some species than in others.

In general, all of the animals studied discriminated visual depth by the time locomotion was possible, but this time varied widely, even among terrestrial species.

Analysis of the cues on which the preference depended suggested that motion perspective is more important than density perspective for the animals in whom it was experimentally isolated. In the hooded rat, it appears to be innate as well, since dark-reared animals discriminated between a deep and a shallow surface when motion perspective was probably the sole basis for differentiation.

The results in general support a hypothesis of innate depth perception, though the presence of a certain kind of environment during growth may be important for late maturing animals. Furthermore, it has been shown that innate mechanisms for discriminating depth may be supplemented by the acquisition of a learned cue.

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